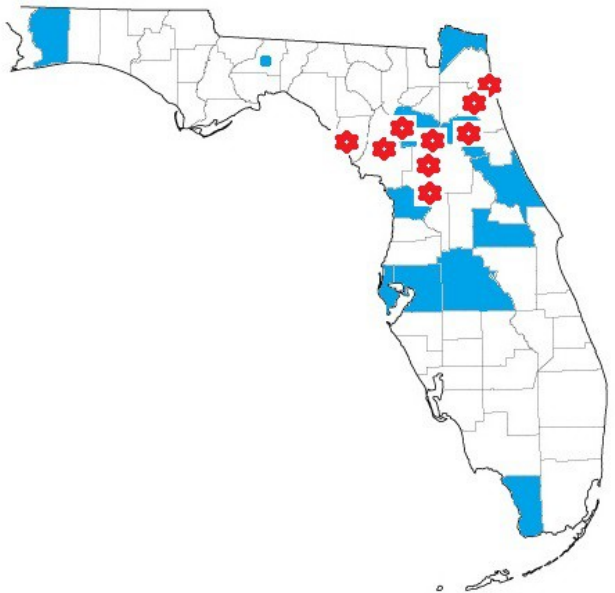
COVID-19 2020

Building a Ham Radio Ventilator

Shameless Plug for March 19 EXERCISE

- Whirlwind Boom 2021 – large scale exercise to train and increase INTEROPERABILITY (“rub shoulders”) between
  - ARES® groups
  - Individual resource units (unaffiliated volunteers)
  - Florida Baptist Disaster Relief (NGO Agency)
  - Florida Div Emergency Management (Governmental Agency)
  - SHARES (Federal DHS backup communications Effort)
- 7 – 9 PM Friday Evening March 19

- Massive tornado volley crossing state of “Roflida” wrecks havoc
- Terrorist bombing in Johnsonville damages Internet
- Incident Action Plan & HSEEP Exercise Plan:



- https://qsl.net/nf4rc/FBDR/2021/2021WhirlwindBoomIC3201.p
- https://qsl.net/nf4rc/FBDR/2021/2021WhirlwindBoomExerciseP
- See qsl.net/nf4rc for more information

Dual-Themed Talk:

Technical Development	**Ham Radio Volunteer Project Management**
All the technical issues that had to be solved to create a useful product that could be easily manufactured in a garage anywhere in the world.	How we harnessed the incredible reservoir of trained experts and meshed with the FDA requirements as best we could.

Benefits of the Amateur Service

§97.1 Basis and purpose.

The rules and regulations in this part are designed to provide an amateur radio service having a fundamental purpose as expressed in the following principles:

(a) Recognition and enhancement of the value of the amateur service to the public as a voluntary noncommercial communication service, particularly with respect to providing emergency communications.

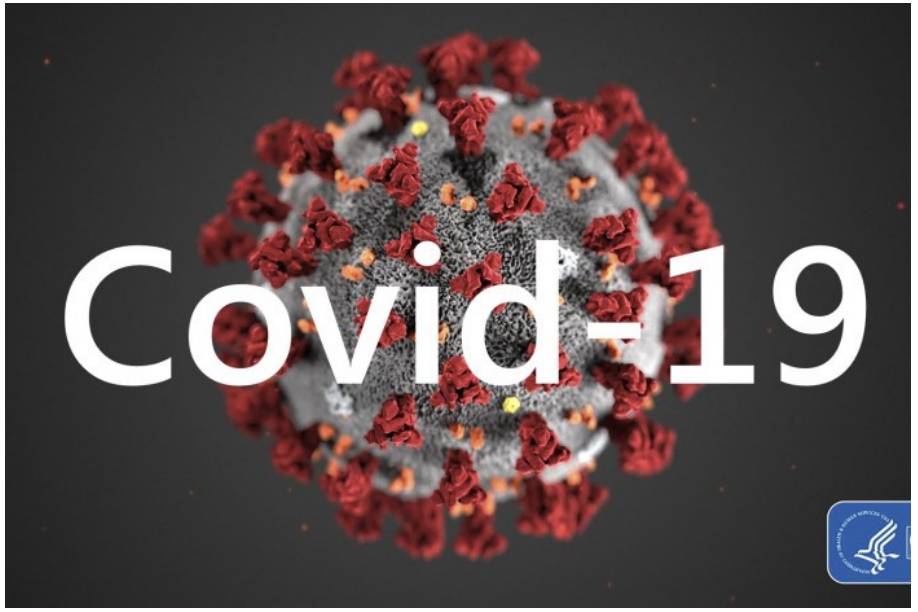
(b) Continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art.

(c) Encouragement and improvement of the amateur service through rules which provide for advancing skills in both the communication and technical phases of the art.

(d) Expansion of the existing reservoir within the amateur radio service of trained operators, *technicians, and electronics experts*.

(e) Continuation and extension of the amateur's unique ability to enhance international

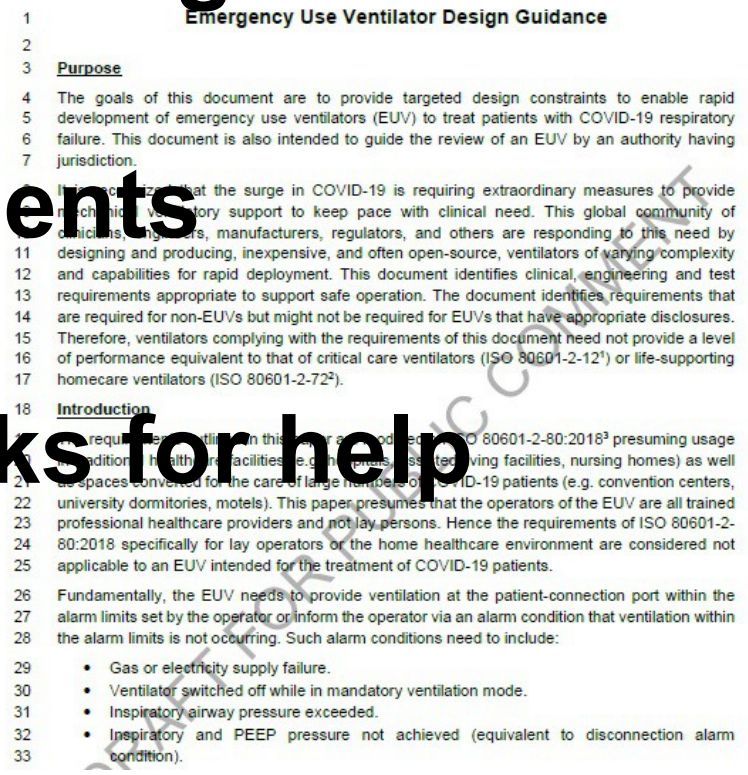
SITREP: We were all going to die by April 19



- New virus – “no human immunity”
- Reports of 3-4% mortality
- Exponential growth expected
- Overwhelming hospitals, bodies stacking up….
- (Even tho this now seems alarmist in retrospect..… it actually did happen in some portions of the world….)

WE NEED VENTILATORS NOW!

- **FDA opens “Emergency Usage Authorization”**
- **“Simple” list of requirements (28 pages)**
- **Sem Lampotang PhD Asks for help**



Emergency Use Ventilator Design Guidance

Purpose

The goals of this document are to provide targeted design constraints to enable rapid development of emergency use ventilators (EUV) to treat patients with COVID-19 respiratory failure. This document is also intended to guide the review of an EUV by an authority having jurisdiction.

In recognition that the surge in COVID-19 is requiring extraordinary measures to provide mechanical ventilatory support to keep pace with clinical need. This global community of clinicians, engineers, manufacturers, regulators, and others are responding to this need by designing and producing, inexpensive, and often open-source, ventilators of varying complexity and capabilities for rapid deployment. This document identifies clinical, engineering and test requirements appropriate to support safe operation. The document identifies requirements that are required for non-EUVs but might not be required for EUVs that have appropriate disclosures. Therefore, ventilators complying with the requirements of this document need not provide a level of performance equivalent to that of critical care ventilators (ISO 80601-2-12[1]) or life-supporting homecare ventilators (ISO 80601-2-72[2]).

Introduction

The requirements for ventilation in this paper are modified from ISO 80601-2-80:2018[3] presuming usage in conditions of healthcare facilities (e.g. hospitals, assisted living facilities, nursing homes) as well as spaces converted for the care of large numbers of COVID-19 patients (e.g. convention centers, university dormitories, motels). This paper presumes that the operators of the EUV are all trained professional healthcare providers and not lay persons. Hence the requirements of ISO 80601-2-80:2018 specifically for lay operators or the home healthcare environment are considered not applicable to an EUV intended for the treatment of COVID-19 patients.

Fundamentally, the EUV needs to provide ventilation at the patient-connection port within the alarm limits set by the operator or inform the operator via an alarm condition that ventilation within the alarm limits is not occurring. Such alarm conditions need to include:

- Gas or electricity supply failure.
- Ventilator switched off while in mandatory ventilation mode.
- Inspiratory airway pressure exceeded.
- Inspiratory and PEEP pressure not achieved (equivalent to disconnection alarm condition).

OFFICIAL FDA PUBLIC COMMENT

Human Ventilation

- Normal breath approx. 500 cc (think ¼ of 2 liter bottle)
- Normal lungs very compliant – so only 25-35 cmH2O pressure
- Equals 0.4 pounds per square inch – air pressure is 15 psi
- Very small pressure but accurately delivered
- Respiratory rate 10-30
- Maintain “end-expiratory” pressure at desired level 5-20 cmH2O (helps keep boggy lungs “open”)

Growing ventilator concern

- USA tens of thousands of ventilators short….
- Strategic cache = 10,000 (Cuomo loudly demanding 40,000)
- Ventilator mortality = 80%
- Go on vent = death sentence
- Need to allow patients to BREATHE on their own if possible
- FDA EUA doesn’t require this
- Lots of confusion.

Ventilator Design Concepts

- Supply CONSTRAINTS
- Normal ventilator parts disappearing
  - Use unconventional parts
- Ventilator valves in very short supply
  - Use sprinkler valves
  - Drive with compressed air (similar pressure)

UF Initial Status

- They had an airway system, but zero way to make it turn on and off…..

- Next slide: the famous Sunday morning kitchen table demo

They need a control system….

- They can’t even test without a control system

Test lung

VIDEO REMOVED FOR SPACE

Ventilator hoses

Arduino Uno

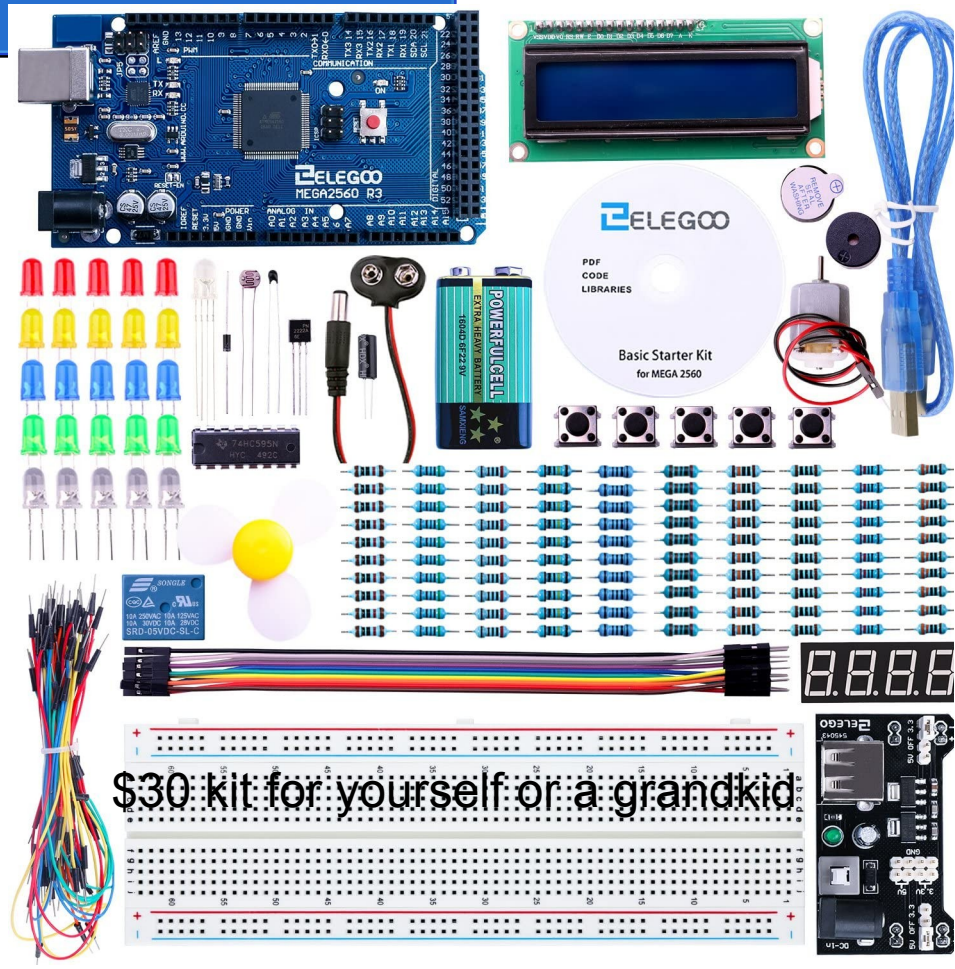
2N3055 transistor driver

MFJ power supply

My Bright Idea….

- Control it with an Arduino

$5 Arduino Nano



Enter Ham Radio Volunteer Project Management

- I needed BRAINPOWER and in a hurry. I knew I didn't know enough to make this happen on the required time frame.
- So…..turn to people who are experts via their proven contributions to amateur radio

FIND My Bright Friends!!!! HELP!!

- Jack Purdum W8TEE – programming author
- Ashhar Farhan VU2ESE – entrepreneur, creator of Bitx; creator of satellite contract company

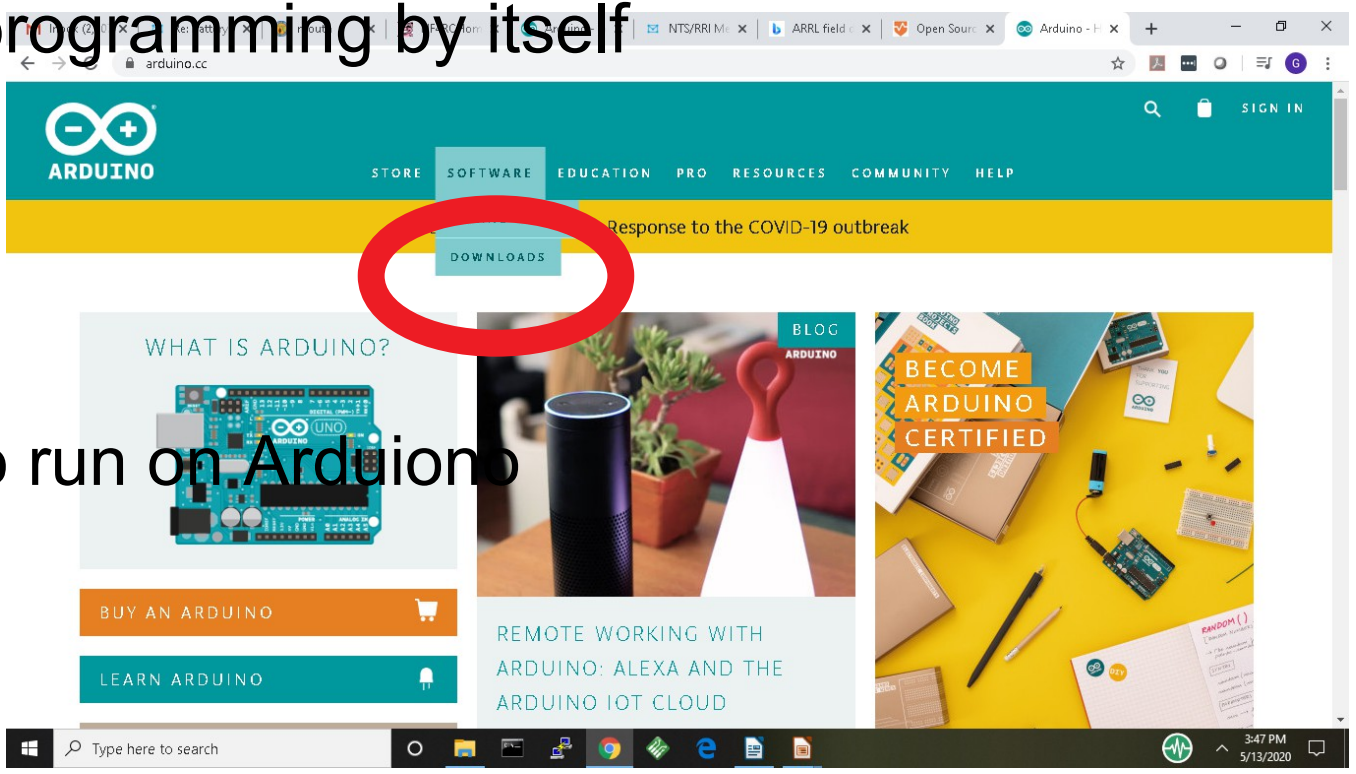
Assembling these brilliant co-workers from Amateur Radio was probably my Biggest contribution to the project...

What is an “IDE”???

- Integrated Development Environment
- Runs on your personal computer.
- Allows you to easily develop and compile working source code.
- Then uploads it to a $3 Arduino, and allows you to watch RS232 serial port outputs EASILY and thereby debug.
- FREE

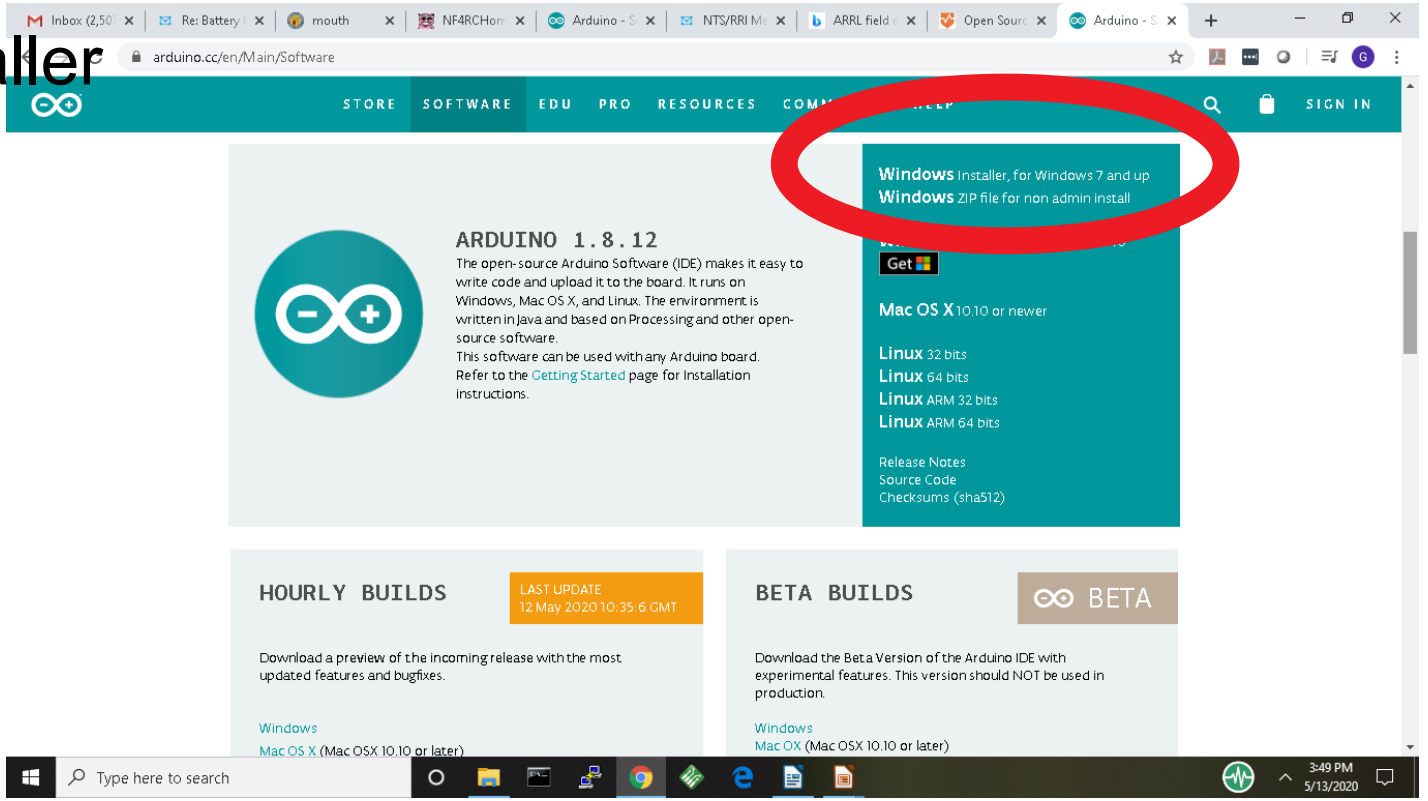
FOR YOU: LOAD THE IDE

- Free system to load software onto Arduino – ANY arduino
- Does not require programming by itself
- Load “sketch”
- Hit button
- Hit another button
- Software begins to run on Arduino



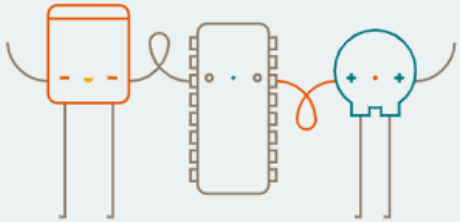
Available Windows & Mac

- Skip the web editor (v e r y s l o w!)
- Windows Installer



Contribute to the Arduino Software

Consider supporting the Arduino Software by contributing to its development. (US tax payers, please note this contribution is not tax deductible). Learn more on how your contribution will be used.



SINCE MARCH 2015, THE ARDUINO IDE HAS BEEN DOWNLOADED 41,992,355 TIMES. (IMPRESSIVE!) NO LONGER JUST FOR ARDUINO AND GENUINO BOARDS, HUNDREDS OF COMPANIES AROUND THE WORLD ARE USING THE IDE TO PROGRAM THEIR DEVICES, INCLUDING COMPATIBLES, CLONES, AND EVEN COUNTERFEITS. HELP ACCELERATE ITS DEVELOPMENT WITH A SMALL CONTRIBUTION! REMEMBER: OPEN SOURCE IS LOVE!

$3 $5 $10 $25 $50 OTHER

JUST DOWNLOAD CONTRIBUTE & DOWNLOAD

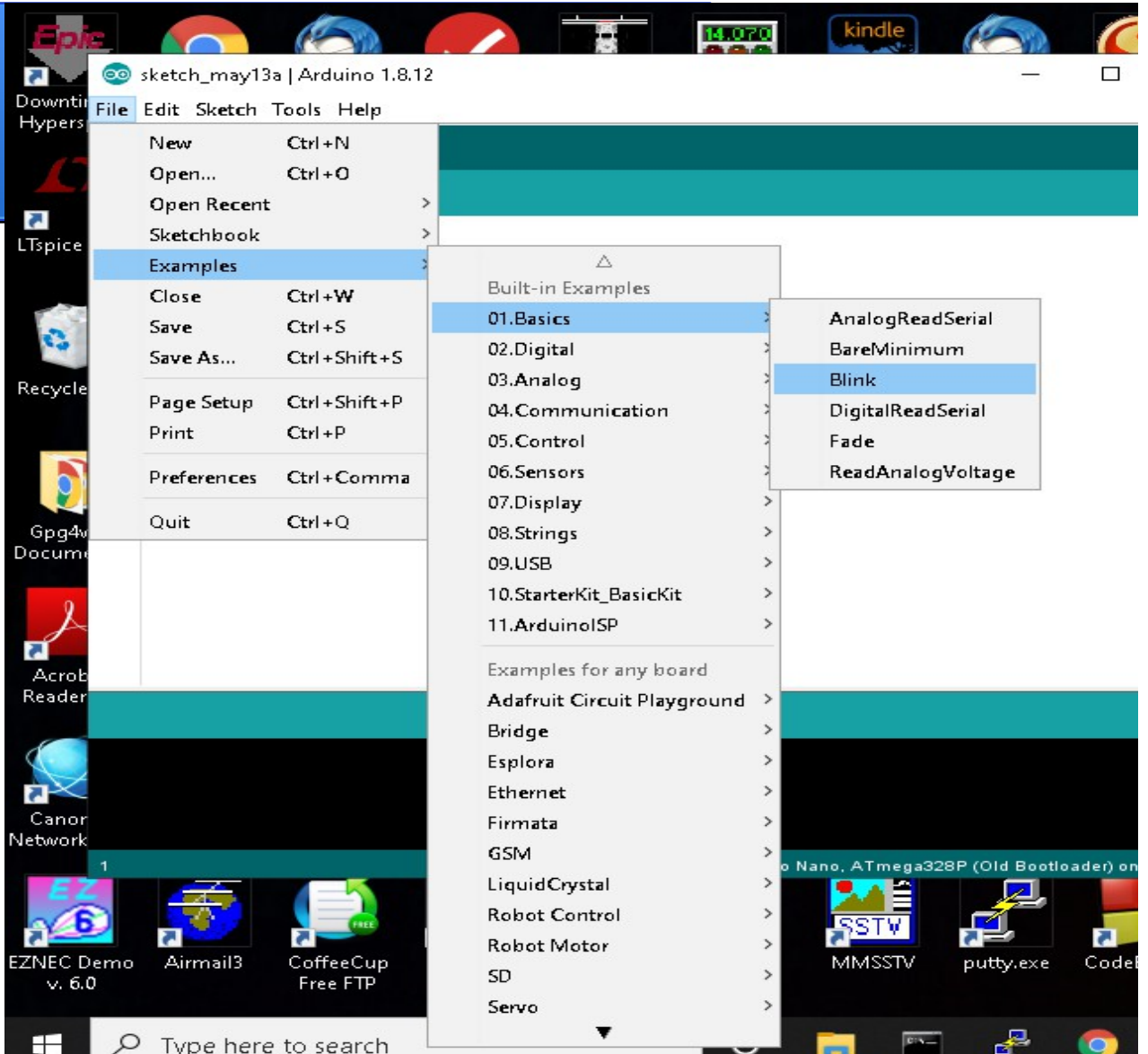
Privacy - Terms

Installing, continued, on your PC

- Click “Open when Done” somehow….
- Answer a prompt YES you want it installed
- Recommend you let it put it wherever it wants….

Self Learning

- Comes preloaded with examples.
- File: Examples:
- Basics : Blink –



Connect USB cable & it loads software!

- Ubitx – all varieties load their software this way
- Many, MANY educational kits
- Can be used to do ordinary programming as well…
- Includes multiple A/D converters (measure voltages)
- Includes multiple Digital outputs
- Includes PWM outputs
- Can drive almost anything: relays, transistors, LCD screens….

I begged for help on Bitx20@groups.io

- **We immediately overwhelmed the forum**
- **Jack Purdum creates a new forum**
  - **VentilatorDevelopers@groups.io**
  - **Hundreds and hundreds of posts, 200 contributors & lurkers**
  - **Code passing every single day**
  - **Engineering discussions all over the place**
  - **Thread after thread after thread**
- **NOW WE HAVE BRAIN-POWER...We need HARDWARE**

VentilatorDevelopers

- 200 developers, readers, lurkers
- >2000 posts, wonderful documentation
- Like GOOGLE for developing ventilator
  - I could post a question and get scholarly replies in minutes to hours as we solved problems.

TECHNICAL:
How to make air go into patient?

- Open inspiratory sprinkler valve – and air just flows out the open end.
- Sem had solved it with a **bicycle inner tube**
- Positioned within inspiratory limb, blows up and obstructs expiratory limb thru a crossover

Durability?

- Inner Tubes ripped after a few thousand cycles
- Need 1,000,000 cycles
- Day by day, improvement to > 300,000 cycles
- Ham volunteer goes over hundreds of thousands – there are so many volunteers who did research level testing, I simply can't list them….but I wrote multiple press releases and tried...

Mark Al Winzenried WA9ZCO

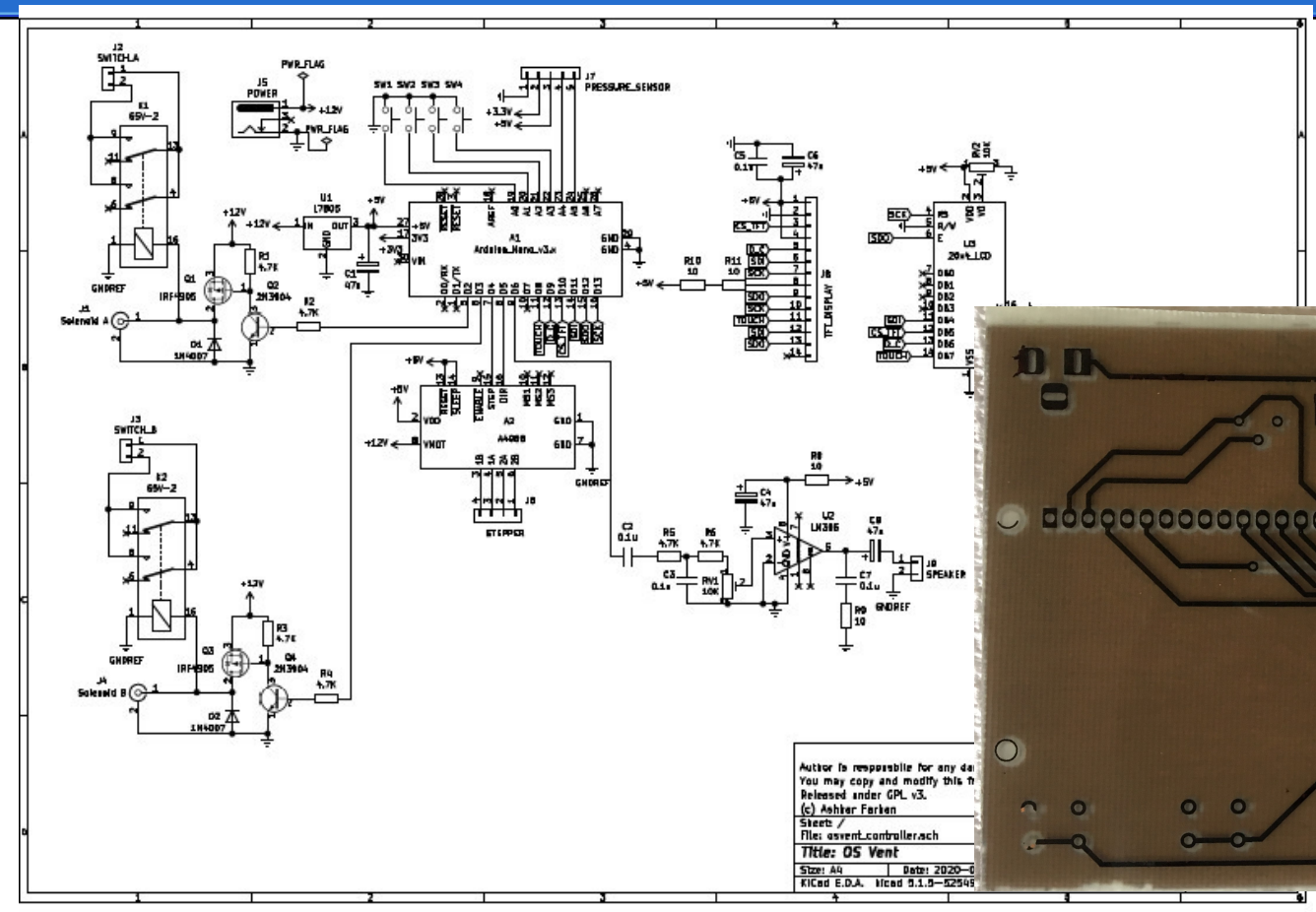
- Figures out how to switch spring in orbit valve and change from NC to NO – **incredibly low resistance** when open
- *Team ignores me when I explain – overwhelmed*
- So days later, I **built** it and showed it was much superior to what they were doing
- Another ham to the rescue!

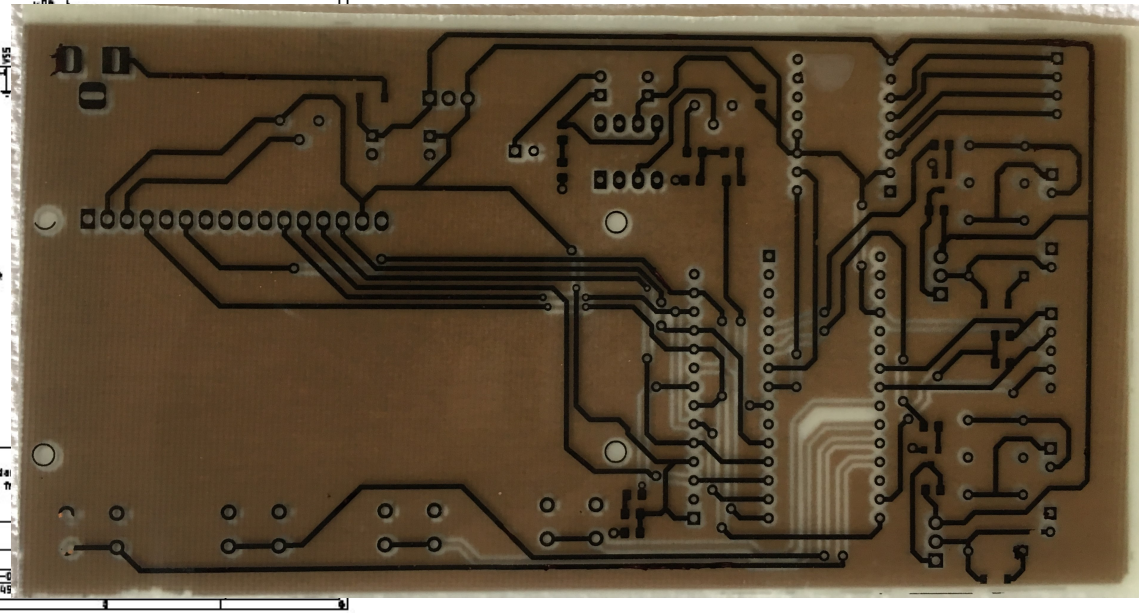
Ham Testers: Volunteer management

- Multiple testors are doing our tests all over the nation
  - Bob Benedict KD8CGH one of the leaders

    He went well over 2 million cycles
- They reach hundreds of thousands of tests in a week or so
- Ashhar is developing control board – input from dozens

Ashhar 0.1 Board—does it work?

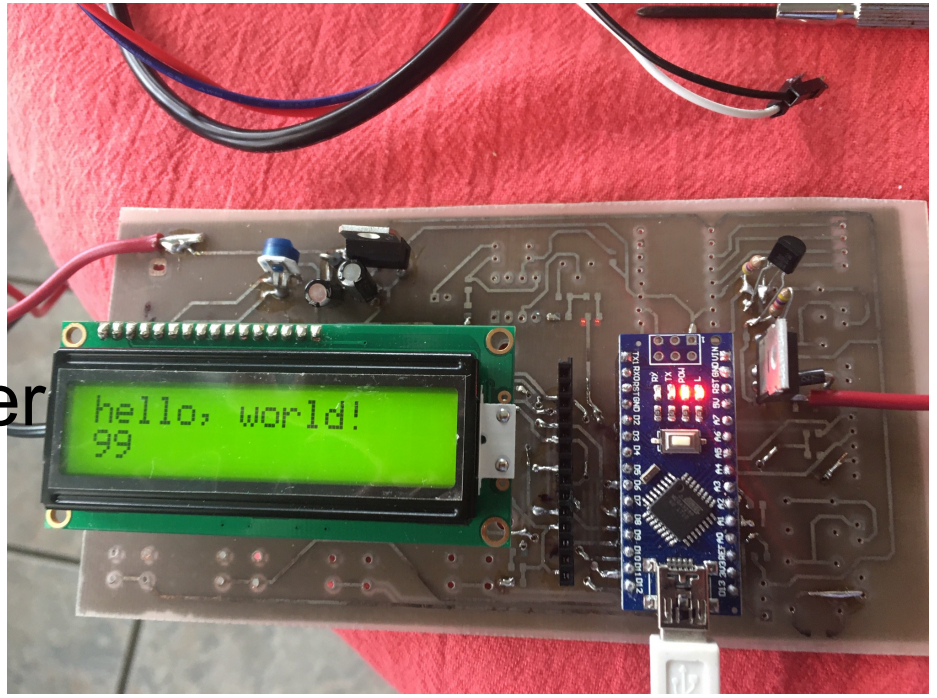




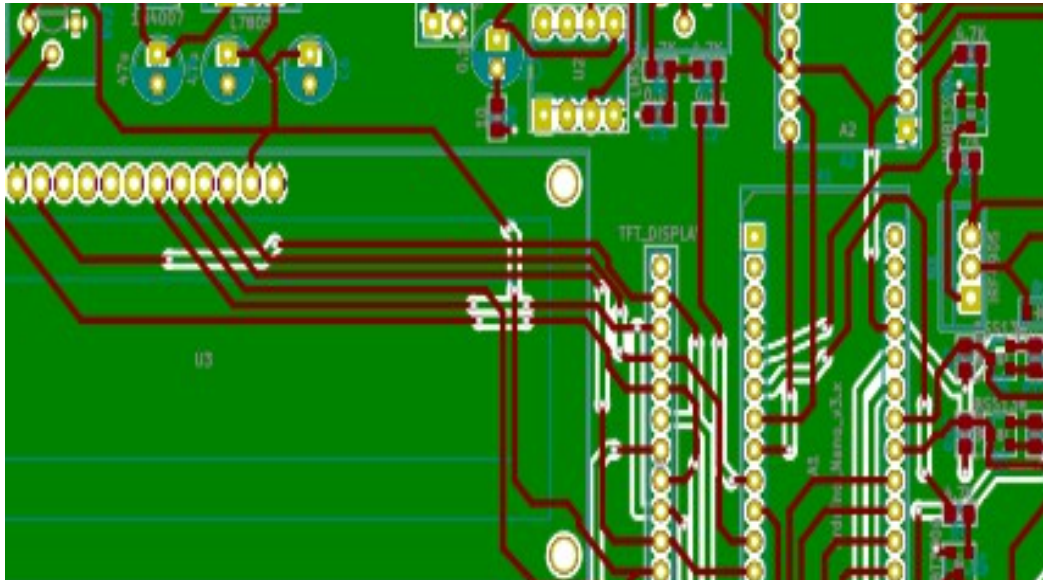
Dr. Gibson hand made this board for us!!!

It works!

- Everything is *hard*.
- We can’t’ get things *built*.
- We can’t *buy parts*
- We can’t get people together
- Everything has to be online



Ashhar Version 1.0

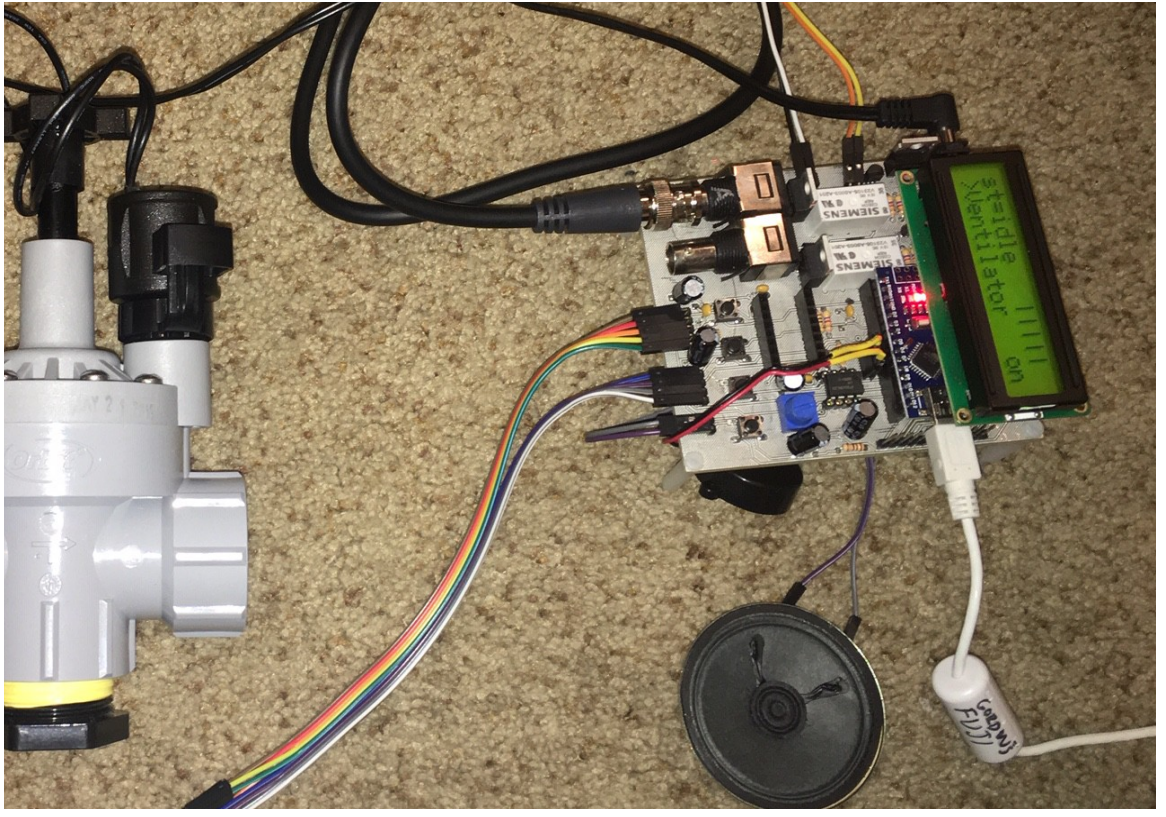


Just as we got Ashhar 0.1 working….
Ashhar comes out with a **completely new board.**

We go with it.
Ashhar builds on KICAD
I only know DIPTRACE
I had to learn some KICAD to deal with his board—I was continuously being force-fed KNOWLEDGE by this crew

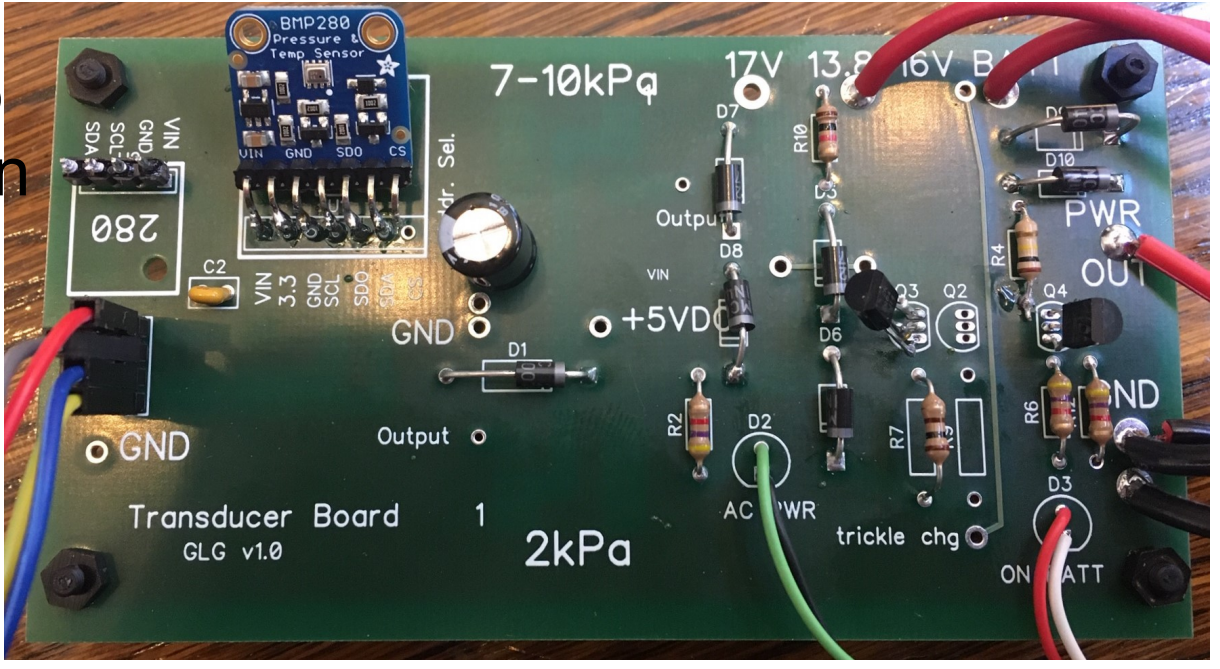
Another ham to the rescue!

- Dr. Stapleton designs his OWN board, has them delivered, solders them together and proceeds to deliver board after board after board!!!
- The UF team is now **overwhelmed with boards**



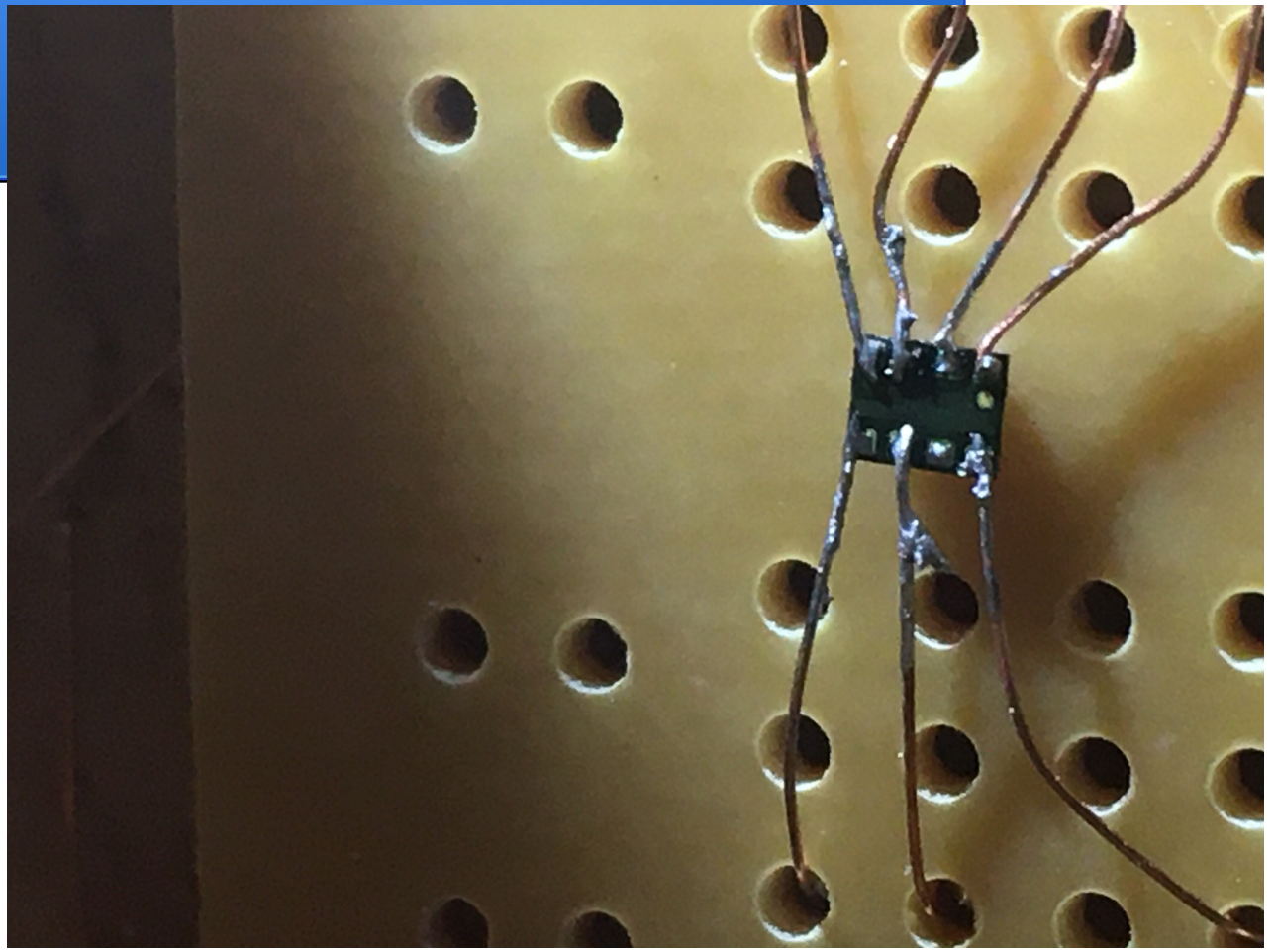
Battery? What Battery?

- On a Friday, Sem says **we have to have a battery.**
- So I design a transducer/battery backup board and have it up within a week..



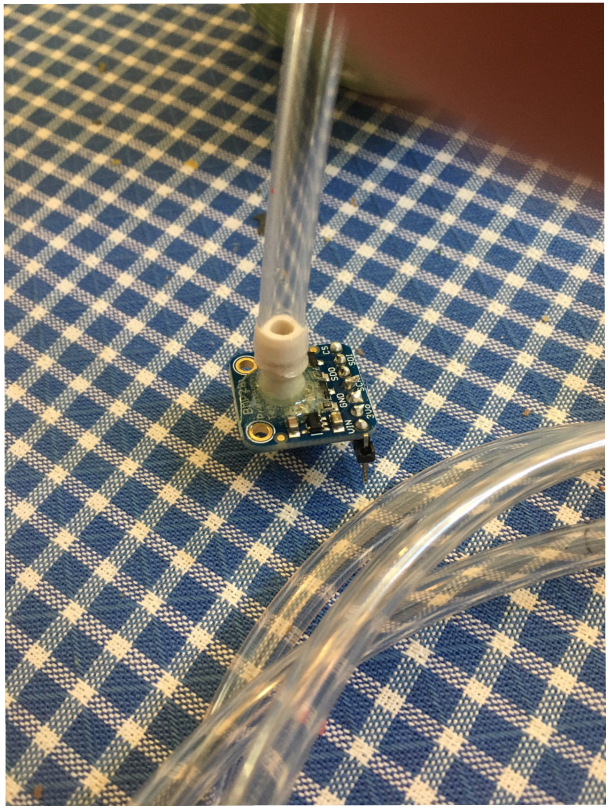
BMP280

- Ashhar has only a 180
- We have only 280’s
- I forgot to note the SIZE of this little device..



Single strands of ethernet standed wire...took 1 hour to solder

Non-differential transducer….no barb—how to connect???

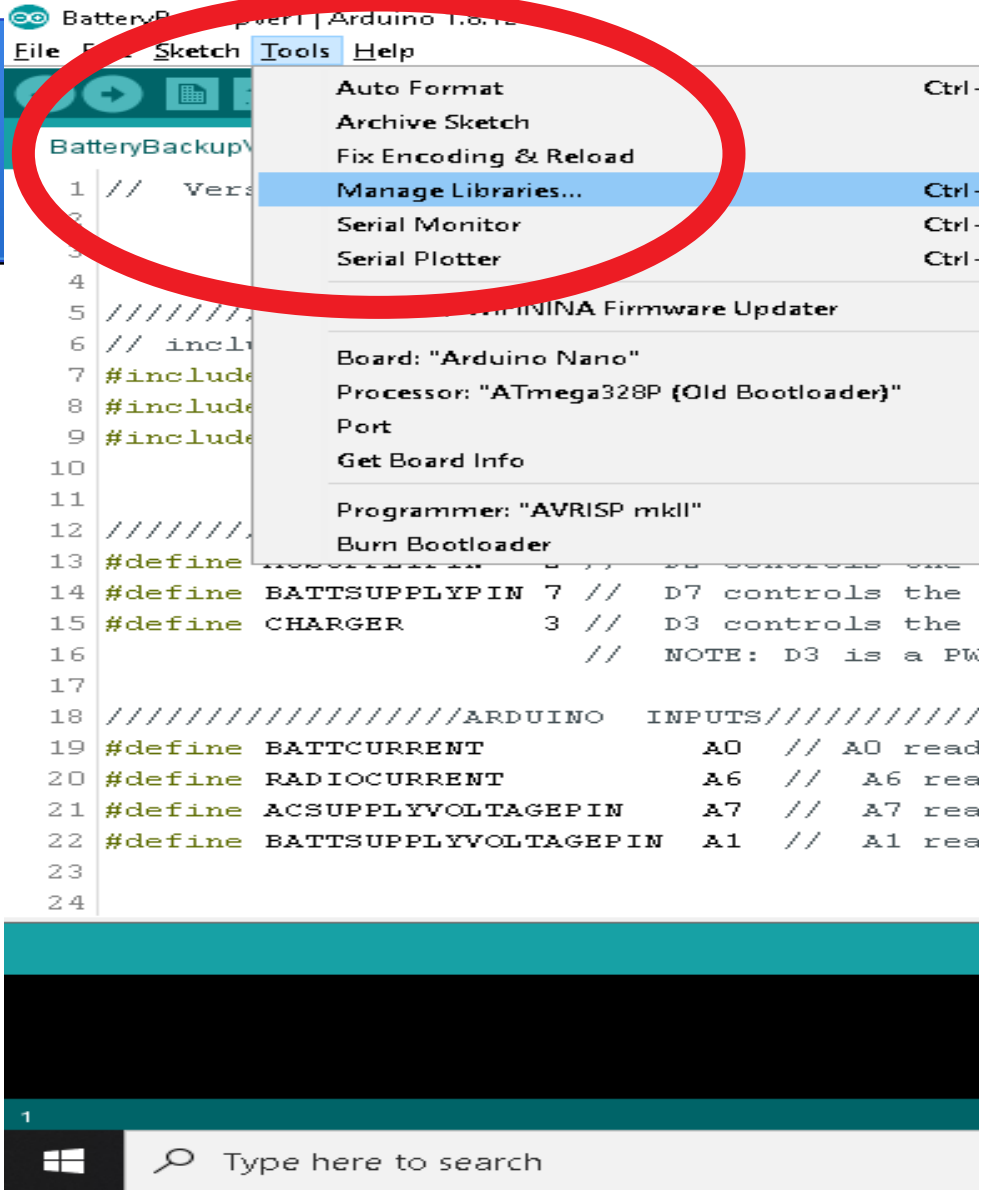


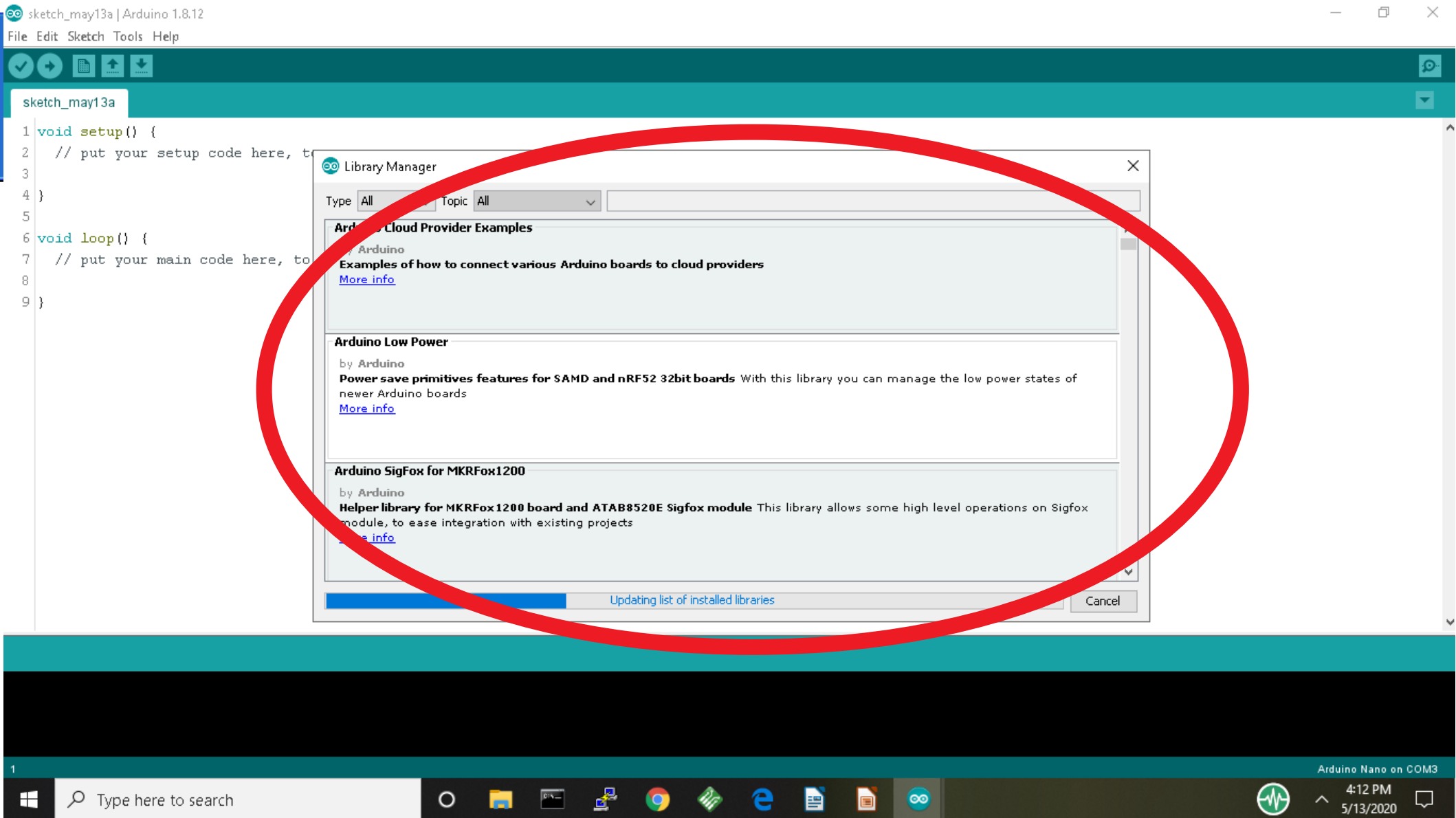
Dave Lizdas' (UF) solution: epoxy a barb to the board to allow connection.

You make a small dab of glue for the first mechanical connection, then you glop more on 2nd try: BE VERY CAREFUL NOT TO OBSTRUCT THE PIN HOLE OF THE BMP280

Libraries?

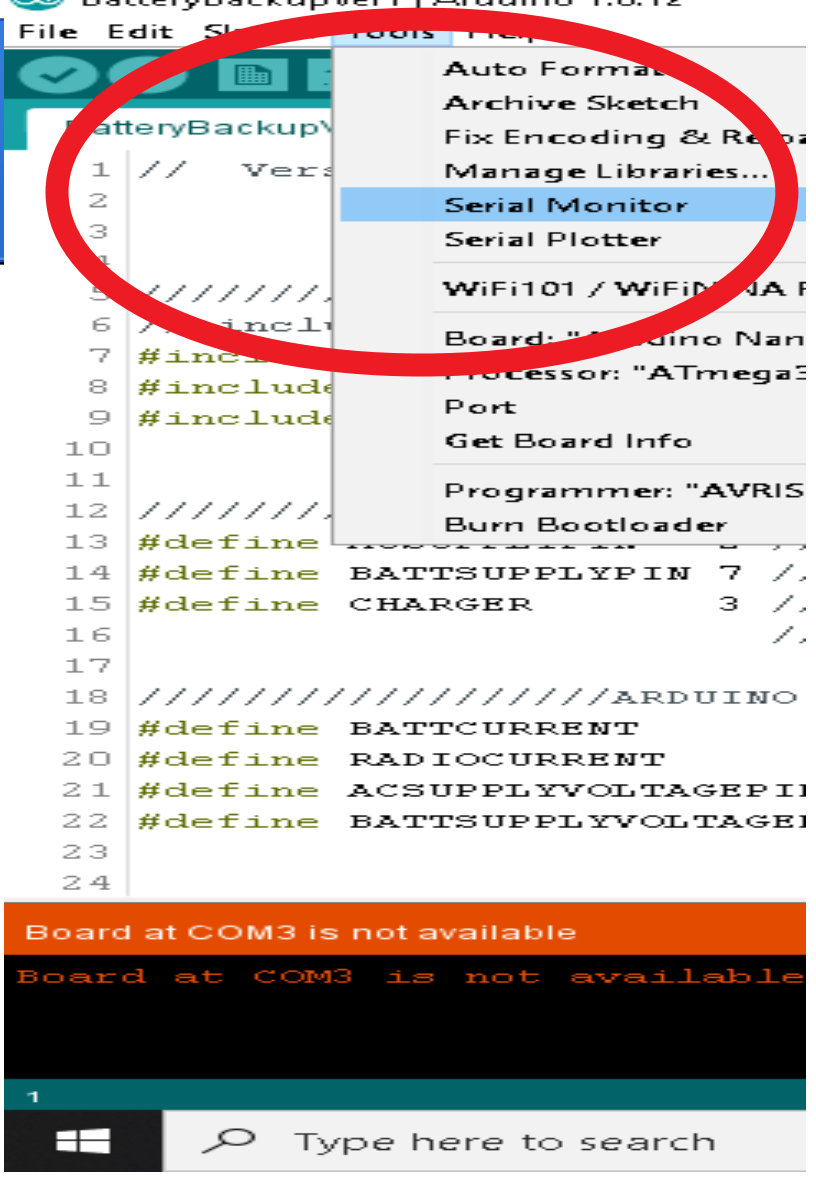
- Most of what we do – the libraries of pre-written routines are already in your system…
- But not always!
- We had to ADD libraries, and we had REAL PROBLEMS with some of them. 180 /280 require DIFFERENT libraries




sketch_may13a | Arduino 1.8.12
File Edit Sketch Tools Help
sketch_may13a
1 void setup() {
2 // put your setup code here, t
3
4 }
5
6 void loop() {
7 // put your main code here, to
8
9 }
Library Manager
Type All
Topic All
Cloud Provider Examples
by Arduino
Examples of how to connect various Arduino boards to cloud providers
More info
Arduino Low Power
by Arduino
Power save primitives features for SAMD and nRF52 32bit boards With this library you can manage the low power states of newer Arduino boards
More info
Arduino SigFox for MKRFox1200
by Arduino
Helper library for MKRFox1200 board and ATAB8520E Sigfox module This library allows some high level operations on Sigfox module, to ease integration with existing projects
Updating list of installed libraries
Cancel
Arduino Nano on COM3
Type here to search
4:12 PM
5/13/2020

Nitty Gritty

- Board Type
- Port (Device Manager time!!)
- Compile
- Upload
- Serial Monitor



Getting the menus right

- Ashhar Farhan wrote the first code for the vent
- I worked on that code for weeks (the date for us “all dying” kept getting pushed back) – we now had a reasonable ventilator
- Ashhar REWROTE the entire menu over a 3-day weekend
- Many more menu possibilities
- I could now add new features—impossible before

I2C Bus-- Technical Morass

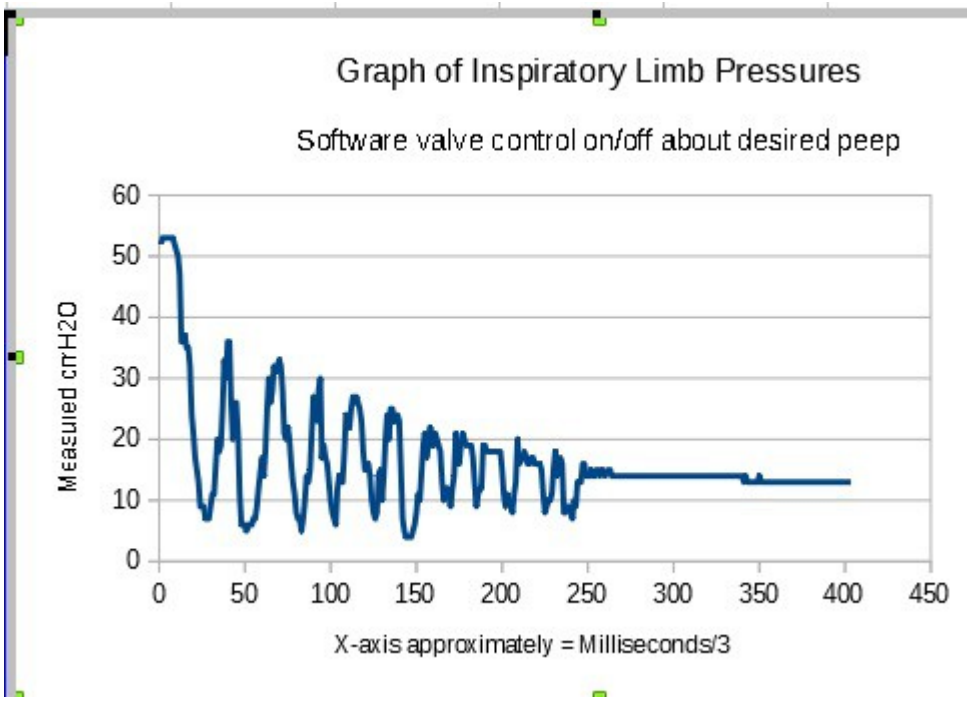
- Huge concerns over “blocking” if a READ failed
- Wrote testing routine to literally pull wires and test
- We generated give-away numbers, and watchdog timer routines so if the machine locked up—it would reboot and discovered it had locked up due to a failed READ – and ignore the I2C bus thenceforth
- Also wrote routine to reset the I2C Bus
- Never ever saw a failure un provoked
- Even TRIED to kill it with Baofeng and WINLINK station – unsuccessful

(Later Developments)

- Replacement libraries were eventually found that significantly reduced the I2C failure issues….
- Tricky libraries...much care needed in utilization.
- Lesson: Don’t hesitate to go right to the developer! Our team was making a simple error in the usage of one library and much time could have been saved by getting the developer involved much earlier.

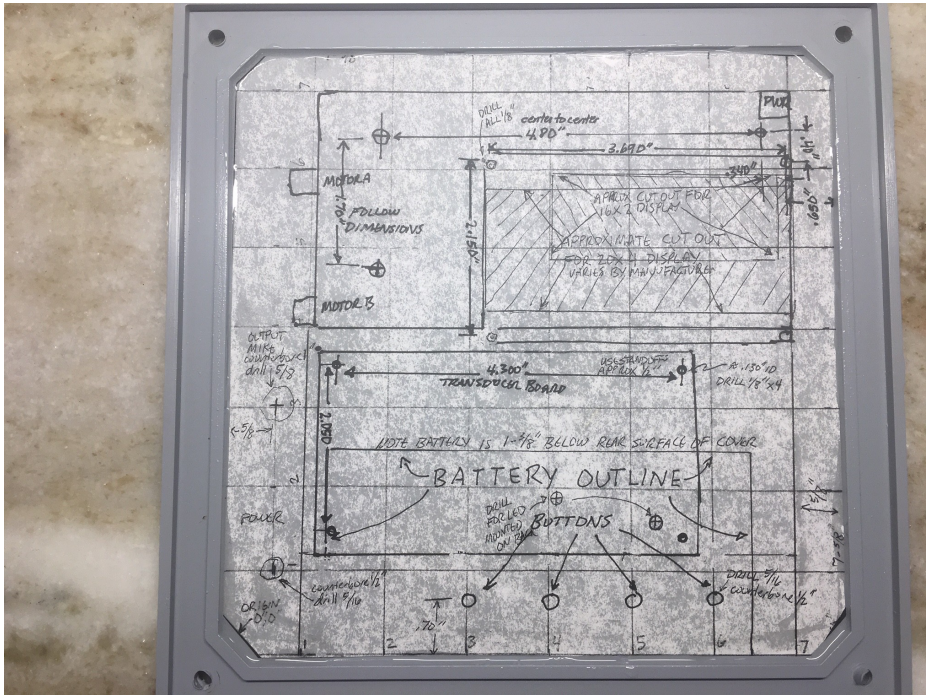
Active Expiration: Controlling PEEP

- With an active expiratory valve we saw new possibilities
- [MISGUIDED MANAGEMENT??]
- Devilishly difficult due to “ringing” in the circuit
- Close the valve: system RINGS pressure
- Exponential decay wrecks havoc with a simple “level

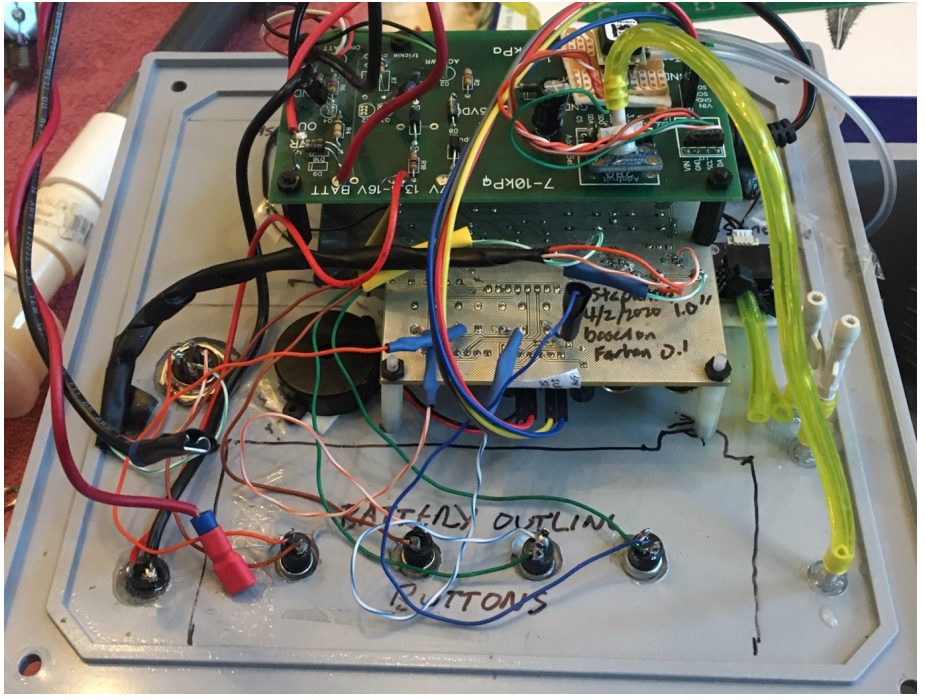


Manufacturing Design

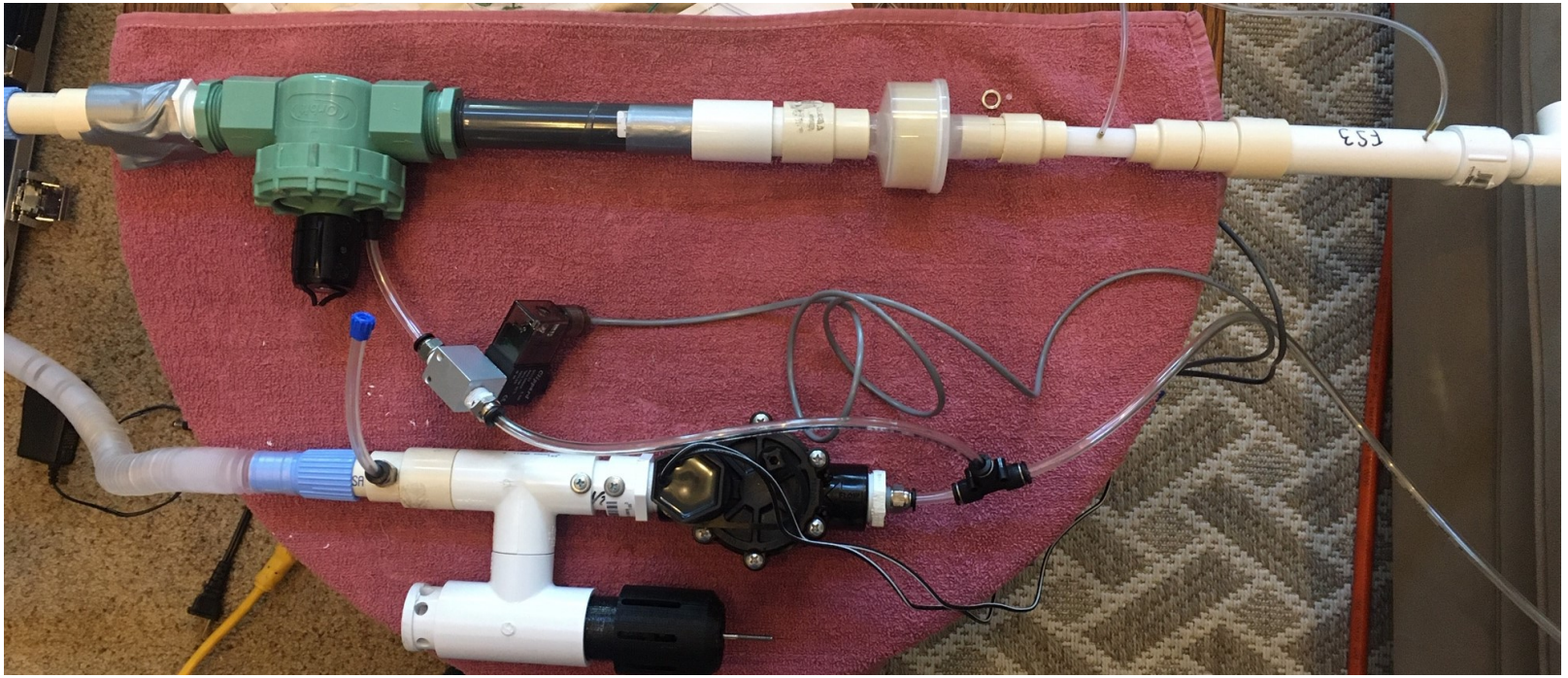
We had become “boxed in” to having a MANUFACTURER….totally unnecessary…. Huge effort went into meeting that requirement



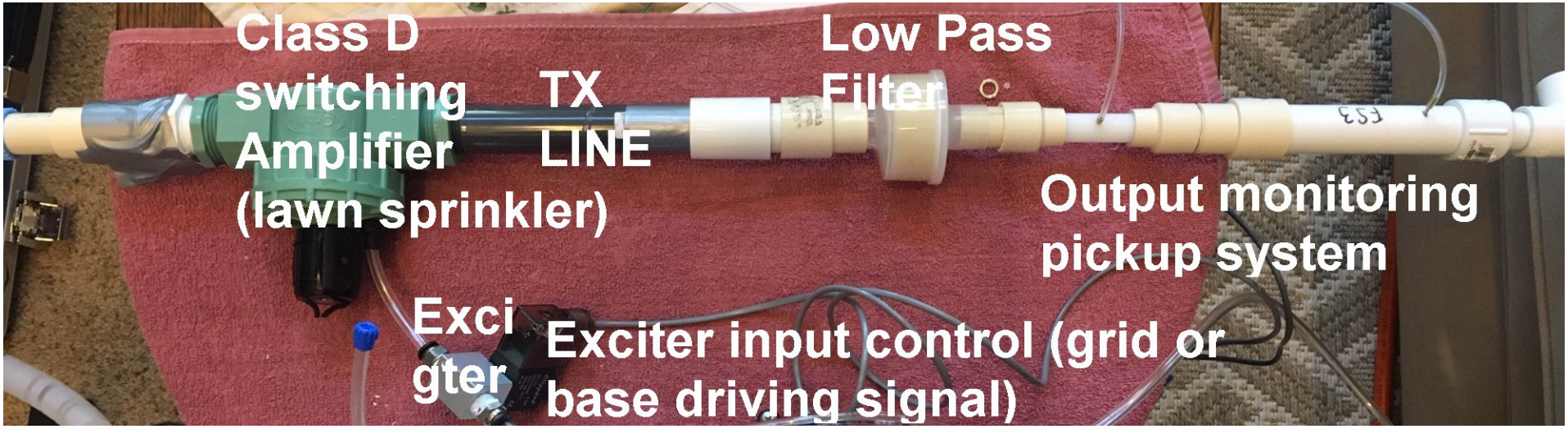
Hams can PROTOTYPE!

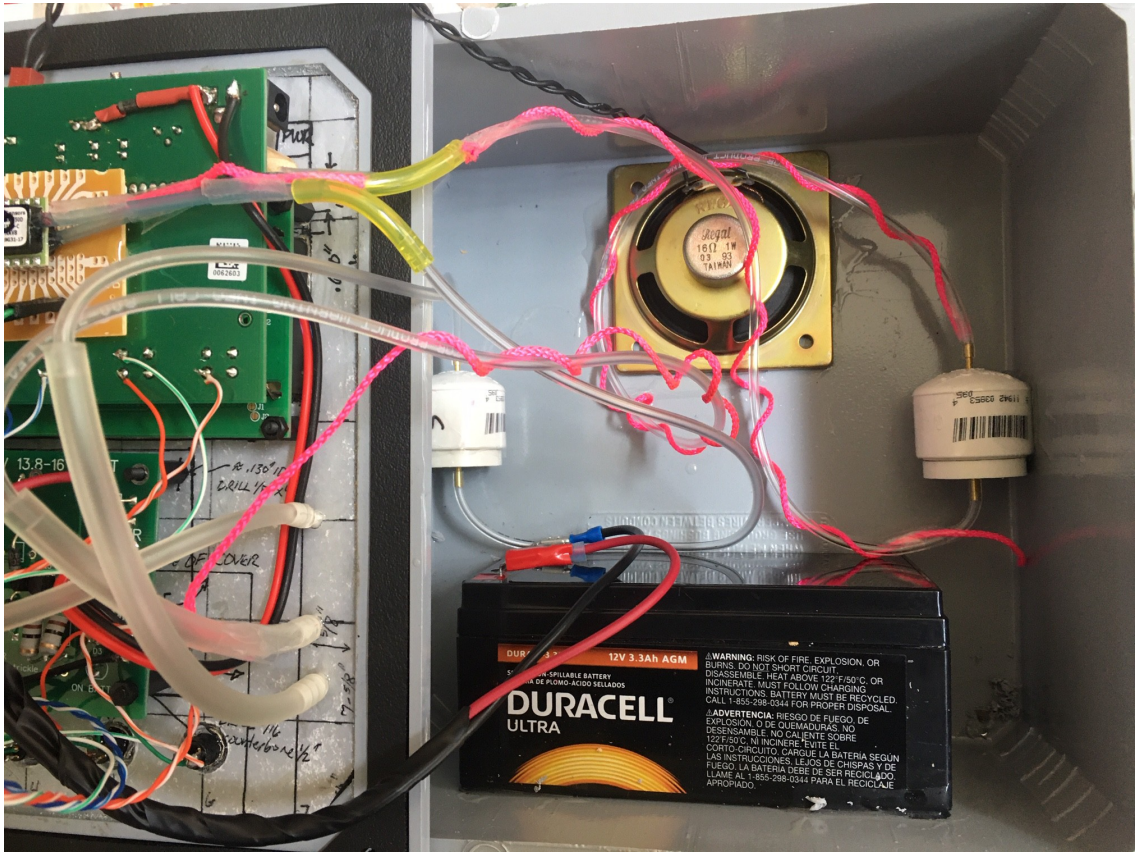


PVC airway portion….

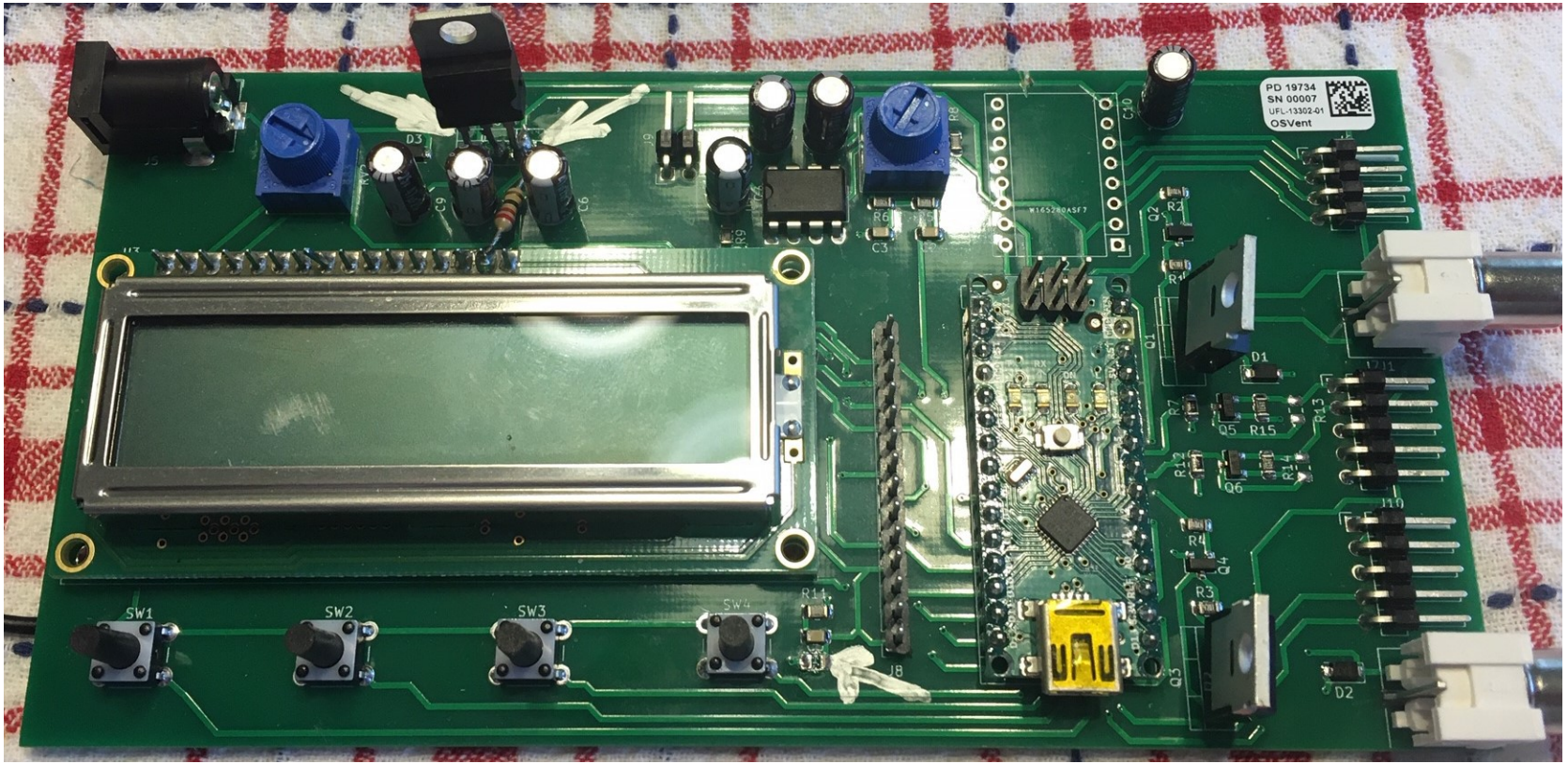


For the FDA, the use of PVC was a real issue….unnecesarily. EXCELLENT management at UF provided data that dealt well with the concerns.


Class D switching Amplifier (lawn sprinkler)
TX LINE
Low Pass Filter
Output monitoring pickup system
Exci gter
Exciter input control (grid or base driving signal)


Regal
16Ω 1W
03 93
TAIWAN
12V 3.3Ah AGM
DURACELL
ULTRA
⚠WARNING: RISK OF FIRE, EXPLOSION, OR BURNS. DO NOT SHORT CIRCUIT. DISASSEMBLE. HEAT ABOVE 122°F/50°C, OR INCINERATE. MUST FOLLOW CHARGING INSTRUCTIONS. BATTERY MUST BE RECYCLED. CALL 1-855-298-0344 FOR PROPER DISPOSAL.
⚠ADVERTENCIA: RIESGO DE FUEGO, DE EXPLOSION, O DE QUEMADURAS. NO DESENSAMBLE. NO CALIENTE SOBRE 122°F/50°C, NI INCINERE. EVITE EL CORTO-CIRCUITO. CARGUE LA BATERIA SEGÚN LAS INSTRUCCIONES. LEJOS DE CHISPAS Y DE FUEGO. LA BATERIA DEBE DE SER RECICLADO. LLAME AL 1-855-298-0344 PARA EL RECICLAJE APROPIADO.

The expensive OVERHEATING boards….$800 of “rush” boards….



Ambient Pressure….oops!

- Changes in atmospheric pressure – bigger effect on ventilator than I realized. The BMP280 while accurate and readily available…..is not a DIFFERENTIAL pressure measurement. Absolute.
- Ham in CA demonstrated big big changes in PEEP (expanding pressure for lungs at end of breath) just in one day, Jan 16 2020
- I soldered in a 2nd BMP280 to measure ambient pressure
- Added code to check ambient pressure EVERY BREATH
- Vent could now be used even in an airplane

Hardware of the FDA Ventilator

- Click the next slide to see video

VIDEO REMOVED FOR SPACE

Ventilator Operation 1

- Click to the next slide to see movie

VIDEO REMOVED FOR SPACE

Ventilator operation 2

- Click to the next slide to see another video

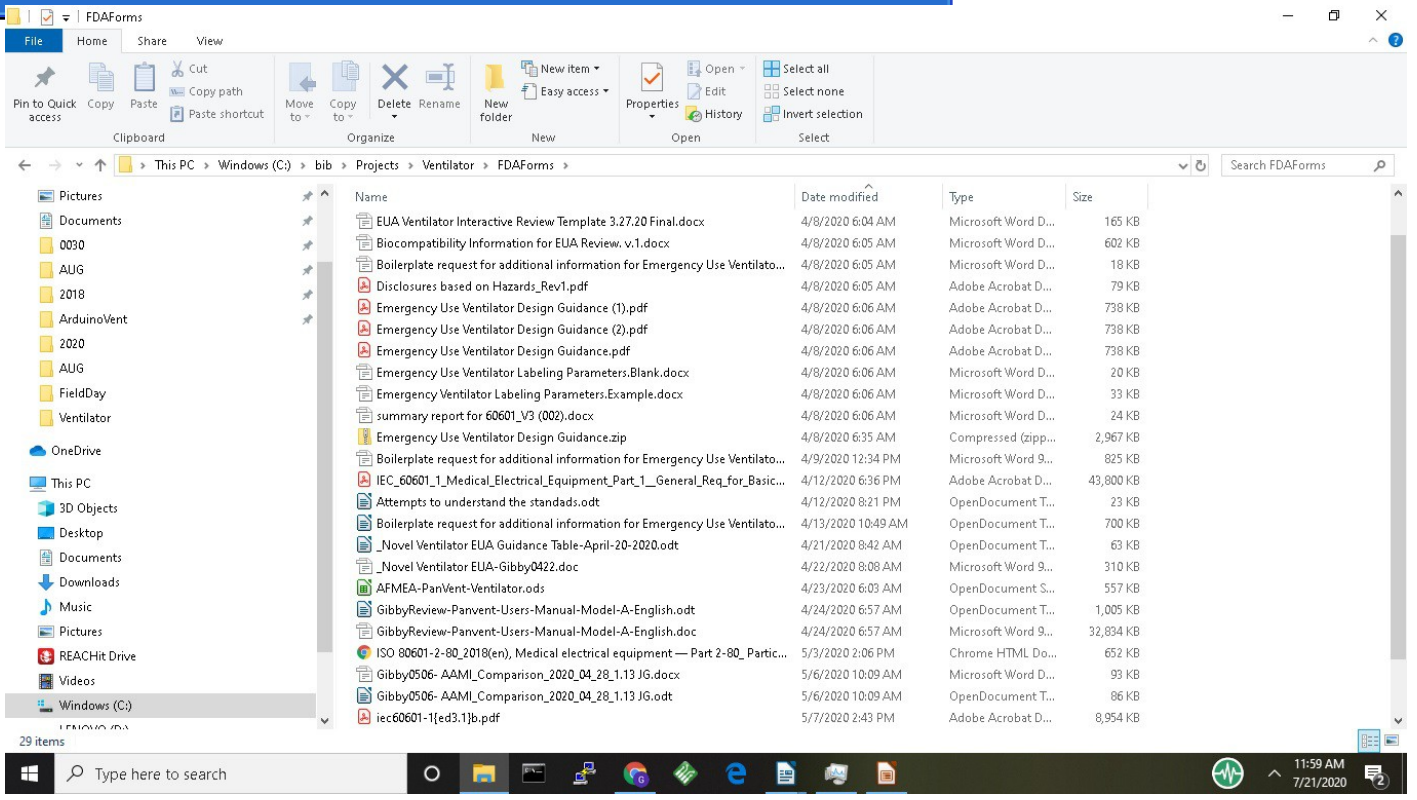
VIDEO REMOVED FOR SPACE

Lessons Learned:
FDA EUA Process

- FDA actually had **very nice process for approving EUA ventilators**.
- Got AAMI (industry group) white paper of requirements (mostly useful)
- Document to explain application process
- Create an application to them….
- Enter into “Interactive” Process
- Formal submission / Decision.

Problem: getting copies of STANDARDS

Many standards COST $$$$ to get a copy….thankfully a UF engineer found copies that were available legally for our purpose.



Documents related to trying to answer FDA approval process.

Emergency Use Application

- University of Florida very new at this.
- Initial lack of legal protection for outside volunteers (UF legal/Dr. Nik Gravenstein worked hard on this: required background checks etc)
- Enlisted volunteer co. with device application FDA experience
- But….the EUA was a new thing…
- So we spun our wheels much more than necessary

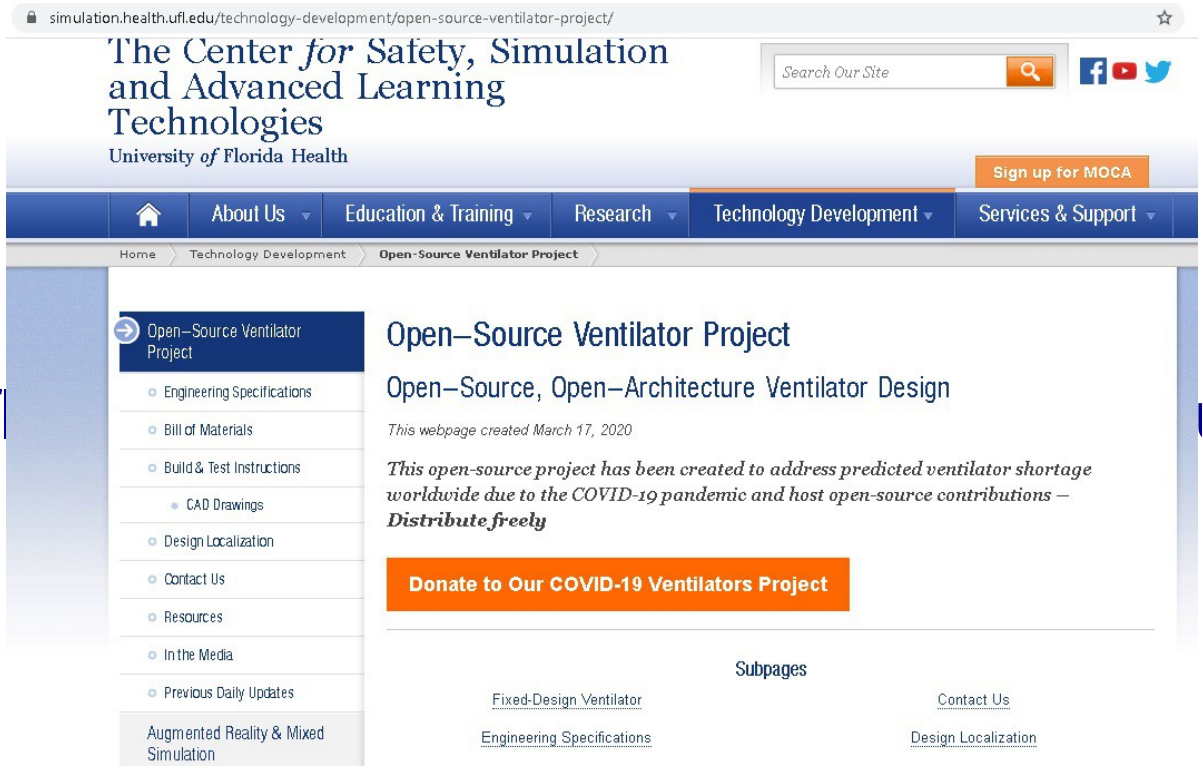
Gotcha's we avoided

- Brief review of FDA documents allowed us to avoid many heartaches….
- Purchased an ISO spec compatible monitor power supply very early….that took care of all our leakage spec requirements
- Aware of the waterproofing requirements
- Good standard ham radio design to avoid ANY connectors with exposed voltages – CB mic connector to connect to solenoids.
- Use the BEST ENGINEERING you know in order to avoid

- Several very simple ventilators (bag valve mask squeezer) were approved.
- JPL created fantastic ventilator – approved (but $$$$)
- All our active expir. Control? **UNWANTED by FDA**
- *Had to be stripped back out!!*
- Lesson: get into interactive EARLIER rather than LATER
- Much simpler submission / Formal Submission now made

The End Result?

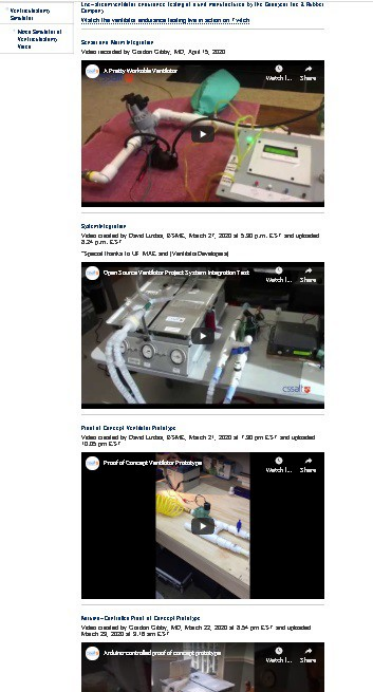
- Still Awaiting outcome
- Most of our ventilator is well documented on the UF site:
- https://simulation.health.uf



VentilatorDevelopers@groups.io has all the source code that I developed and many reports.

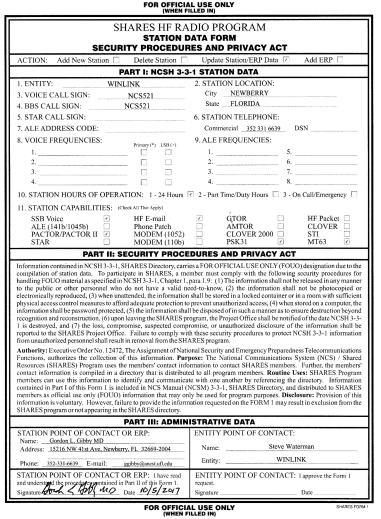
The CSSALT page has many specifications and videos.

One could easily manufacture one or more versions from the information….but having the FDA-approved version (when / if it exists) would be more valuable.



Shameless mention of other Alachua County ARES® - related Projects

- HSEEP-based deployment exercises
- Emergency Comms Conference
- Shelter web server
- VHF Winlink linbpq server
- HF WINLINK/SHARES gateways
- BOOKS!



FOR OFFICIAL USE ONLY
(WHEN FILLED IN)

SHARES HF RADIO PROGRAM
STATION DATA FORM
SECURITY PROCEDURES AND PRIVACY ACT

ACTION: Add New Station ☐ Delete Station ☐ Update Station/ERP Data ☑ Add ERP ☐

PART I: NCSH 3-3-1 STATION DATA

1. ENTITY: WINLINK
2. STATION LOCATION: City NEWBERRY State FLORIDA
3. VOICE CALL SIGN: NC5521
4. BBS CALL SIGN: NC5521
5. STAR CALL SIGN:
6. STATION TELEPHONE: Commercial 352 331 6639 DSN
7. ALE ADDRESS CODE:
8. VOICE FREQUENCIES: (Primary (*) USB (+))
9. ALE FREQUENCIES:
10. STATION HOURS OF OPERATION: 1 - 24 Hours ☑ 2 - Part Time/Duty Hours ☐ 3 - On Call/Emergency ☐
11. STATION CAPABILITIES: (Check All That Apply)

SSB Voice	☑	HF E-mail	☑	GTOR	☐	HF Packet	☐
ALE (1418/1045b)	☐	Phone Patch	☐	AMTOR	☐	CLOVER	☐
PACTOR/PACTOR II	☑	MODEM (1052)	☐	CLOVER 2000	☐	STI	☐
STAR	☐	MODEM (1108)	☐	PSK31	☑	MT63	☑

PART II: SECURITY PROCEDURES AND PRIVACY ACT

Information contained in NCSH 3-3-1, SHARES Directory, carries a FOR OFFICIAL USE ONLY (FOUO) designation due to the compilation of station data. To participate in SHARES, a member must comply with the following security procedures for handling FOUO material as specified in NCSH 3-3-1, Chapter 1, para 1.9: (1) The information shall not be released in any manner to the public or other personnel who do not have a valid need-to-know, (2) the information shall not be photocopied or electronically reproduced, (3) when unattended, the information shall be stored in a locked container or in a room with sufficient physical access control measures to afford adequate protection to prevent unauthorized access, (4) when stored on a computer, the information shall be password protected, (5) the information shall be disposed of in such a manner as to ensure destruction beyond recognition and reconstruction, (6) upon leaving the SHARES program, the Project Office shall be notified of the date NCSH 3-3-1 is destroyed, and (7) the loss, compromise, suspected compromise, or unauthorized disclosure of the information shall be reported to the SHARES Project Office. Failure to comply with these security procedures to protect NCSH 3-3-1 information from unauthorized personnel shall result in removal from the SHARES program.

Authority: Executive Order No. 12472, The Assignment of National Security and Emergency Preparedness Telecommunications Functions, authorizes the collection of this information. **Purpose:** The National Communications System (NCS) / Shared Resources (SHARES) Program uses the members' contact information to contact SHARES members. Further, the members' contact information is compiled in a directory that is distributed to all program members. **Routine Uses:** SHARES Program members can use this information to identify and communicate with one another by referencing the directory. Information contained in Part I of this Form 1 is included in NCS Manual (NCSM) 3-3-1, SHARES Directory, and distributed to SHARES members as official use only (FOUO) information that may only be used for program purposes. **Disclosure:** Provision of this information is voluntary. However, failure to provide the information requested on the FORM 1 may result in exclusion from the SHARES program or not appearing in the SHARES directory.

PART III: ADMINISTRATIVE DATA

STATION POINT OF CONTACT OR ERP:
Name: Gordon L. Gibby MD
Address: 15216 NW 41st Ave, Newberry, FL 32669-2004
Phone: 352-331-6639 E-mail: ggibbs@atsnet.nf.edu

ENTITY POINT OF CONTACT:
Name: Steve Waterman
Entity: WINLINK

STATION POINT OF CONTACT OR ERP: I have read and understand the procedures contained in Part II of this Form 1.
Signature: Gordon L. Gibby MD Date: 10/5/2017

ENTITY POINT OF CONTACT: I approve the Form 1 request.
Signature Date

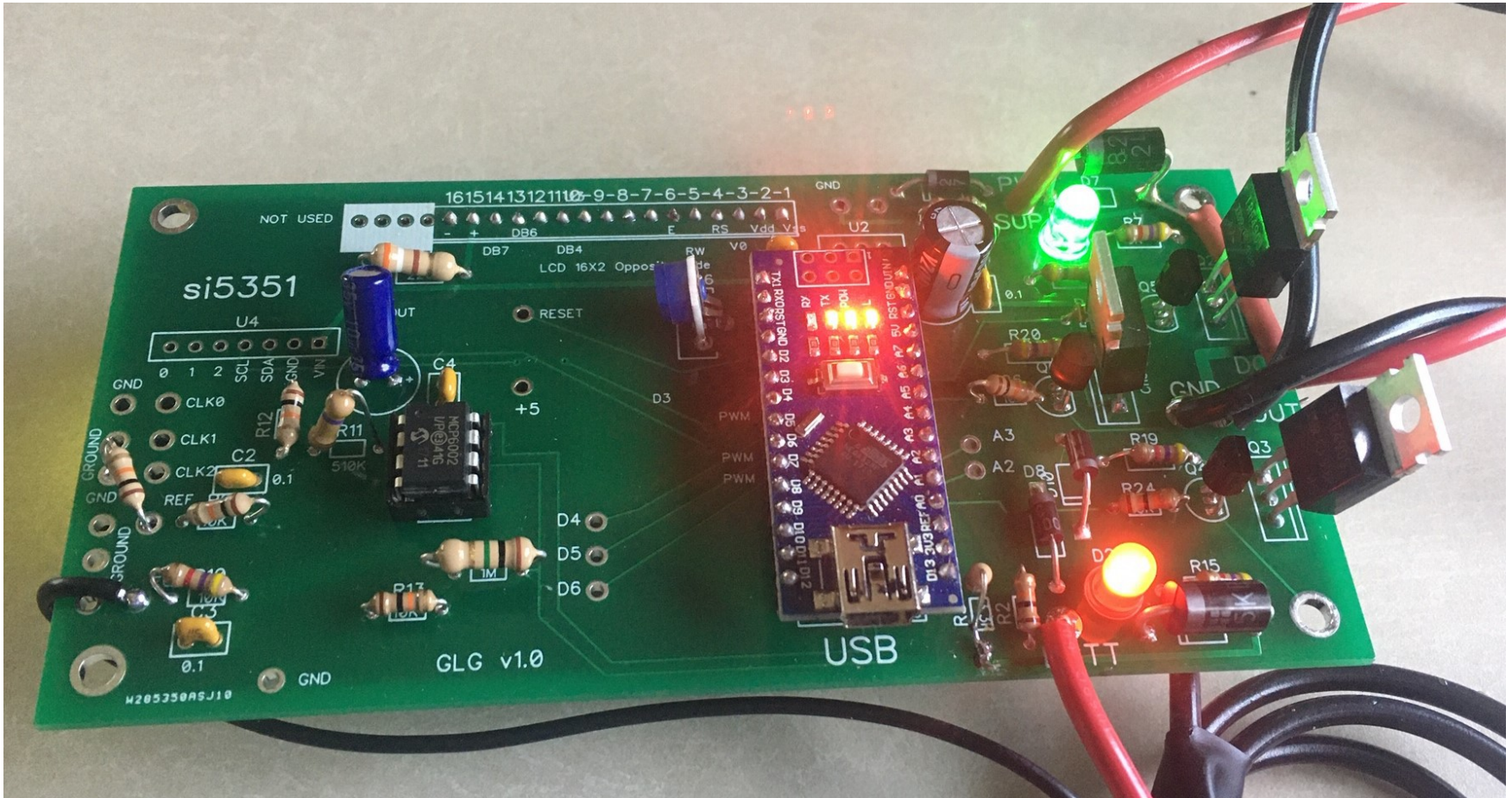
FOR OFFICIAL USE ONLY
(WHEN FILLED IN)

SHARES FORM 1

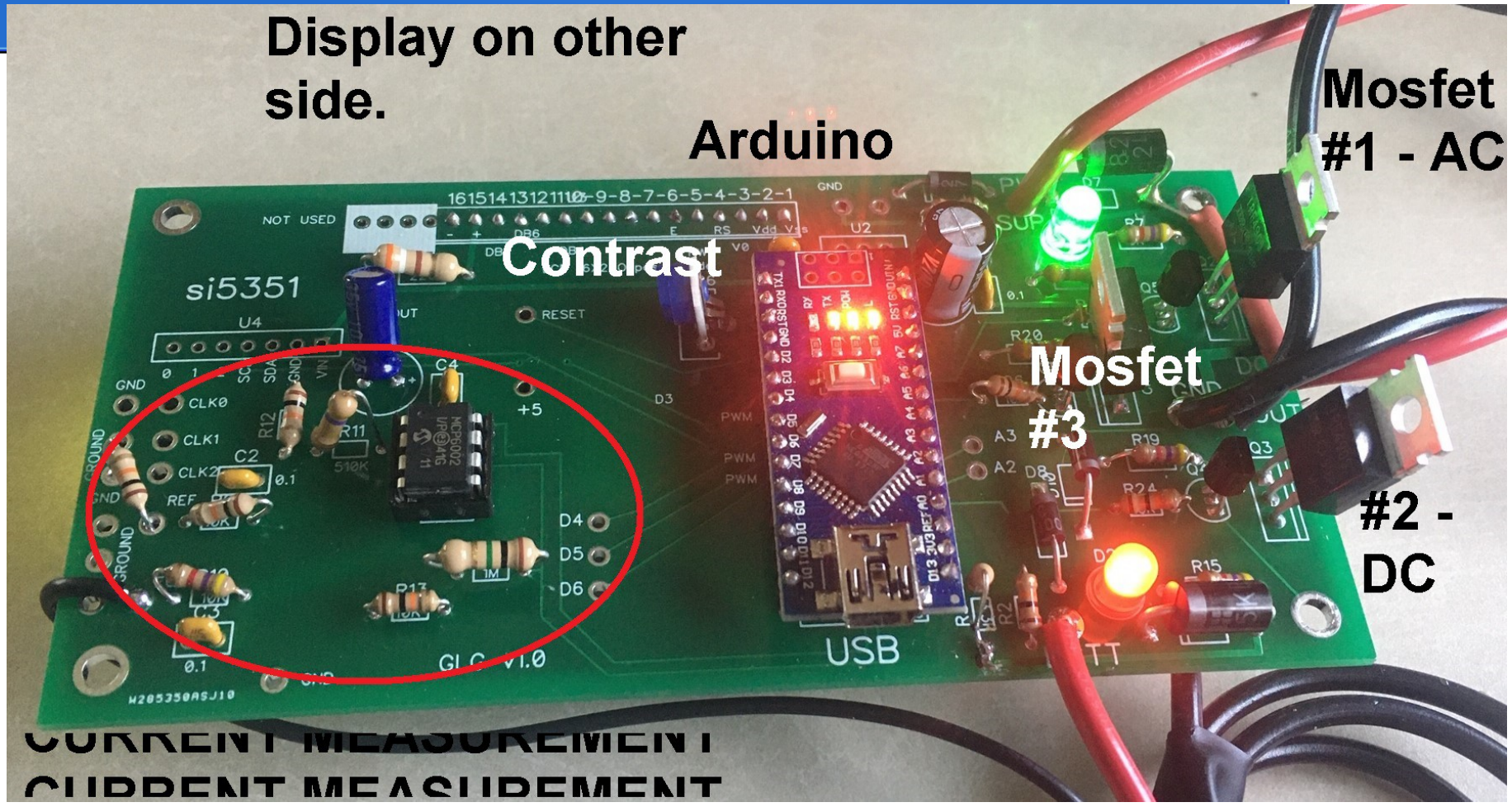
SIDE PROJECT: Battery Backup Board Hardware

- Ashhar introduced me to P-channel MOSFETs – sprinkler driver! (IRF4905)
- Built small battery charger for the transducer board
- Why not build a REAL switcher/charger???

Assembled Board 5”x2.5”



Parts


Display on other side.
Arduino
Contrast
Mosfet #1 - AC
Mosfet #3
#2 - DC
si5351
USB
CURRENT MEASUREMENT

- Next slide: testing setup

Test Setup

VIDEO REMOVED FOR SPACE

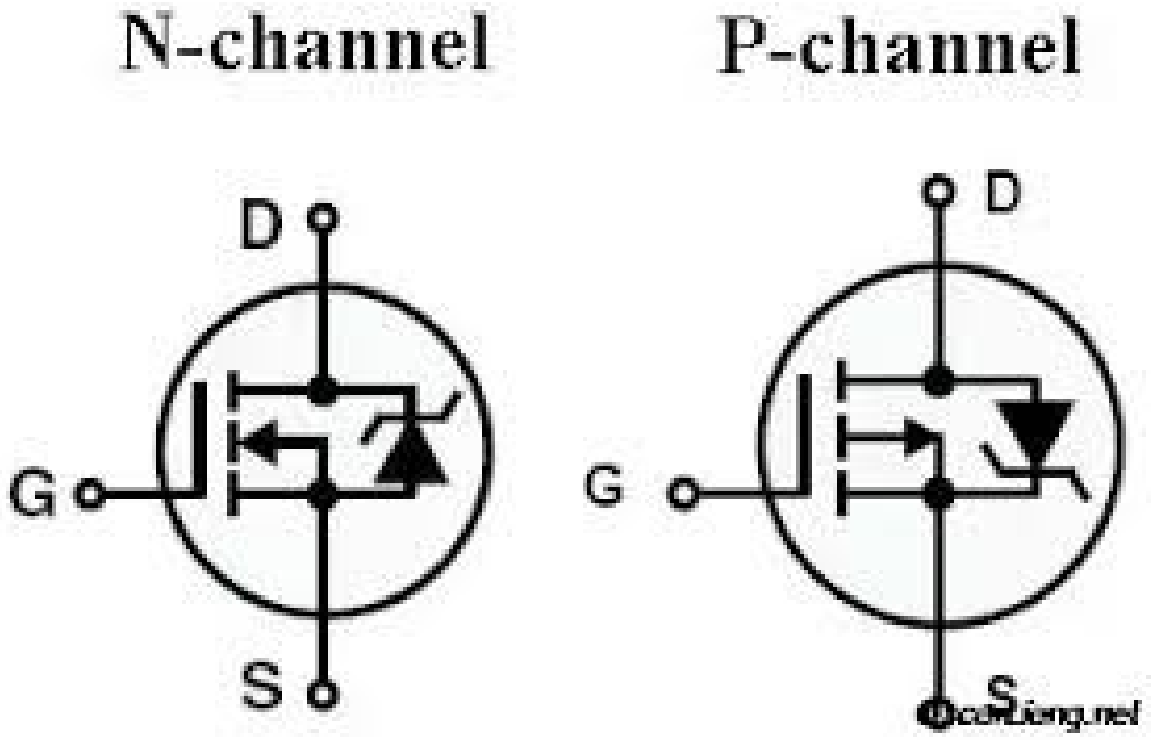
Charging Movie

- *Projects*/BatteryBackup/Charging1.mov
-

Operation Movie

VIDEO REMOVED FOR SPACE

Tricky vertical channel MOSFET!!



THAT ZENER DIODE **WILL** CONDUCT IN ITS FORWARD DIRECTION!!!

IF YOU DON'T PAY ATTENTION TO THIS….YOUR SUPPOSED SWITCH MAY BE ALWAYS ON!!

I ~~THOUGHT~~ I HAD PAID ATTENTION TO THIS…..

I GOOFED

- My DC control mosfet happily passed current thru its diode directly from the AC side to the battery….right around my exquisite charging system…..and totally uncontrolled (think: large current possible)

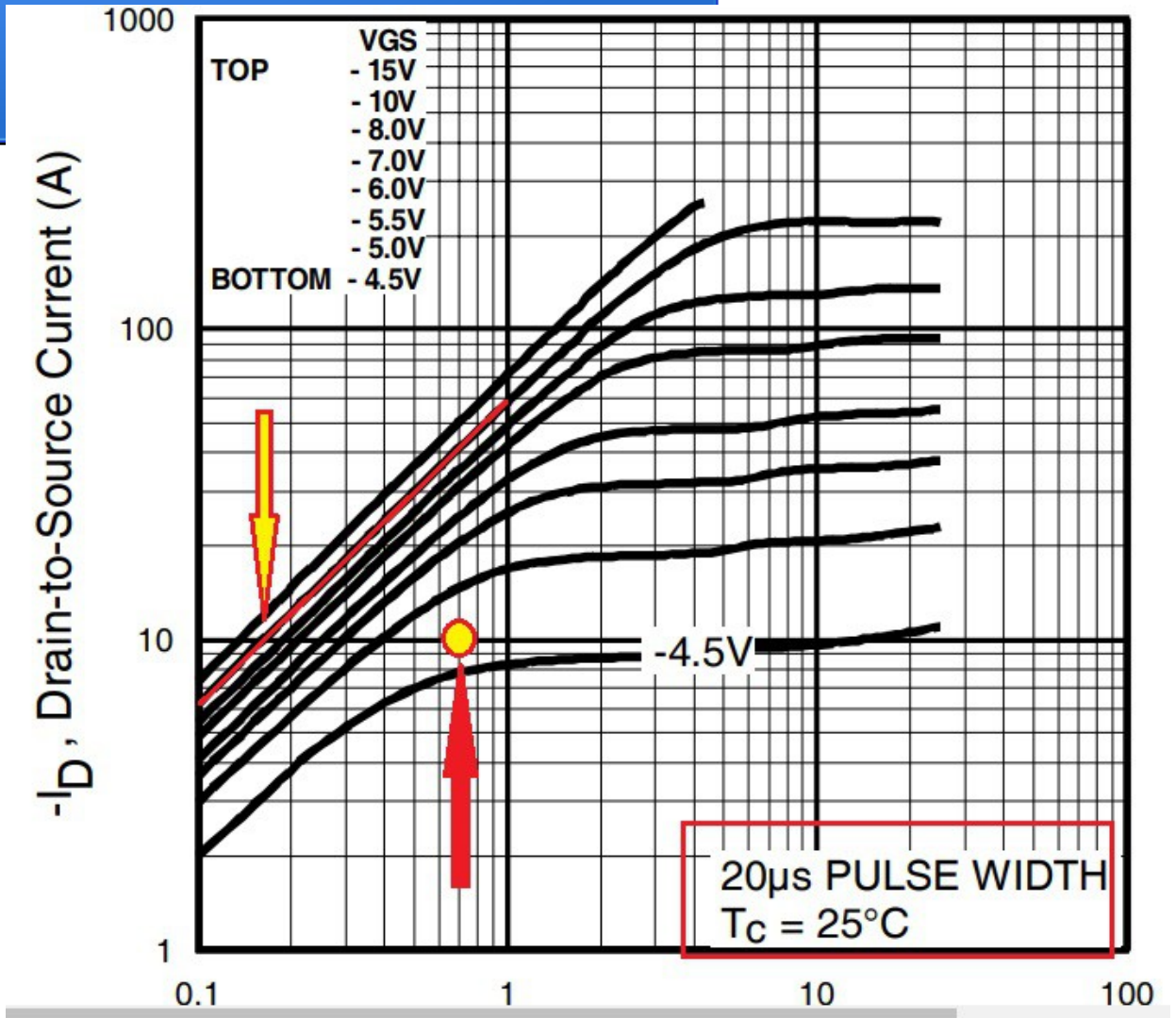
Solution:

- Rewired the mosfets to have **three in series** in a column:
- Power supply at top….
- TOP: controls power supply on/off
- ---- OUTPUT TAP IS HERE
- MIDDLE: “charging” mosfet determines if current goes toward battery
- BOTTOM: determines if battery sends current up to output.
- Battery at the bottom of the board.

ISSUES

- As expected, even FAT traces are too slender….replace with real wire from large “islands” over to MOSFETS on heatsink.
- HEAT – mosfets run around 0.5 volts or more...so with 20 amps...dissipating 0.6x20= 12 watts….
- Gotta keep the semiconductor junction below 170 C
- Need heatsinks commensurate with your usage.

- Amazon-purchased IRF4905's aren't performing as expected
- Modest heatsink gets me success at up to 10A current (~ 50 watts RF output)



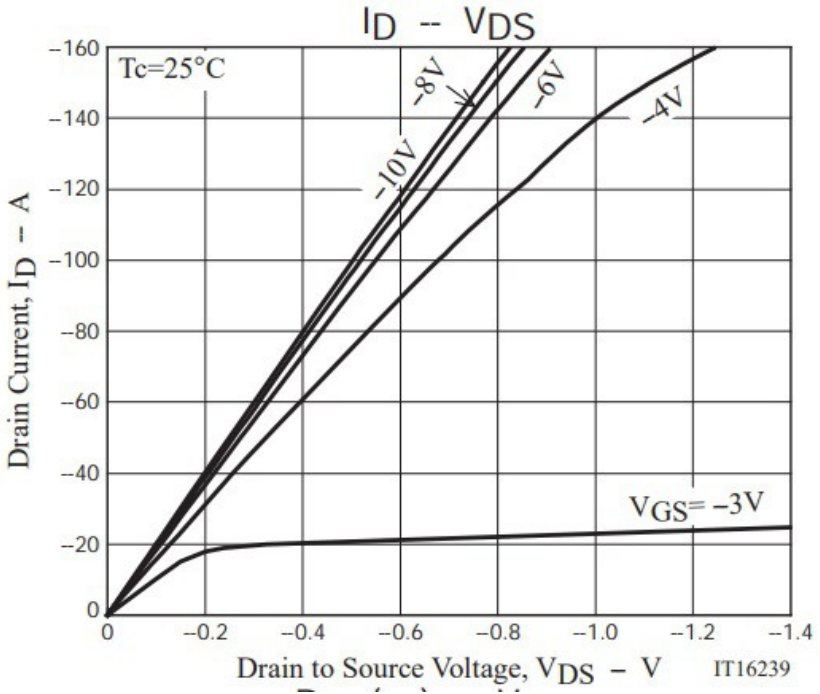
3X better MOSFETS

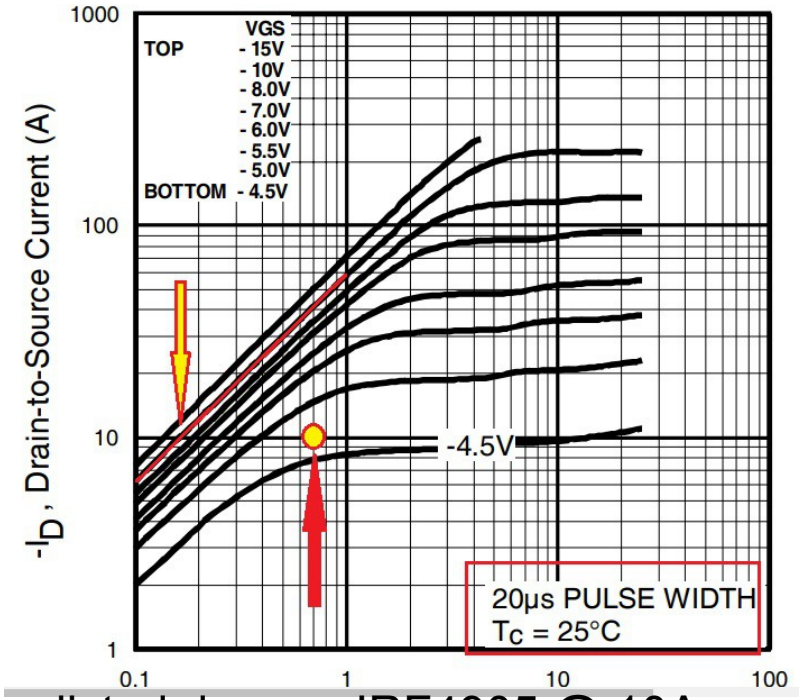
- IRF4905: Rds-on 0.020 ohms
- BMS3003-1E (ON Semiconductor) Rds-on 0.005 ohms
  https://www.digikey.com/product-detail/en/on-semiconductor/B
- SQP90P06-07L_GE3 (VISHAY) Rds-on 0.0056 ohms

  https://www.digikey.com/product-detail/en/vishay-siliconix/SQP90P0

  –
- Important to study thermal characteristics; different manufactures specify various ways. Pay attention!

BMS3003 much better choice

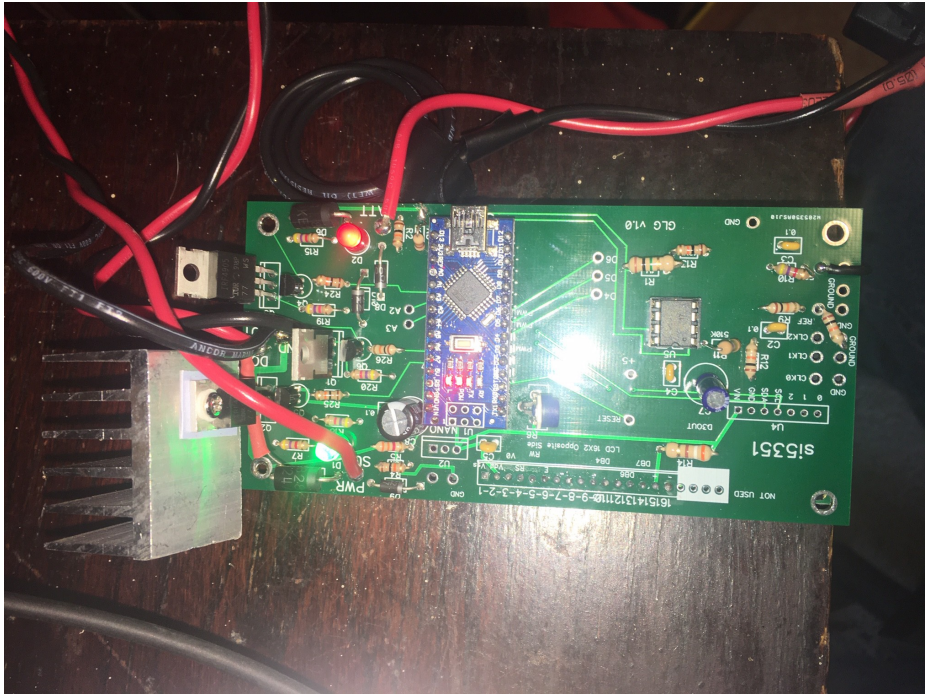




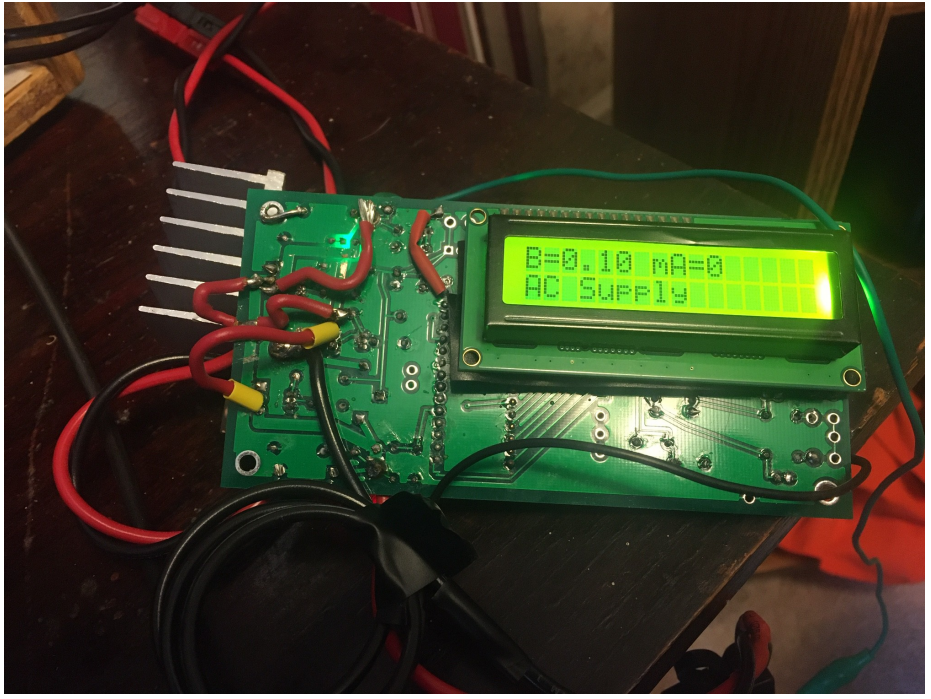
BMS3003 device passes 30A with same predicted drop as IRF4905 @ 10A
Rds-on is approx 5 milli-ohms.

- Prelim results with 0.005 ohm devices extremely encouraging. Expect a successful project
- Measurement of battery charge current/ pulse width charge current control – algorithms for multiple different battery chemistries
- Measurement of usage current – may be able to add “battery gauge” to indicate remaining energy.

Simple Heatsinks



IRF4905
Works well for 10A (50 Wout solid)



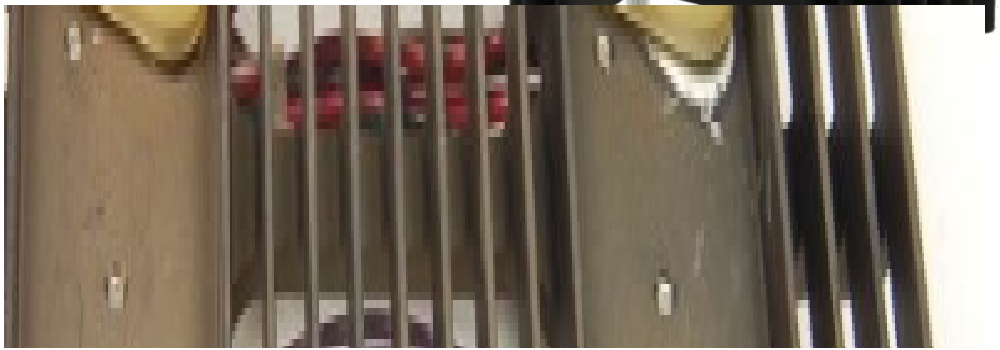
Estimated costs

- DigikeyCart: https://www.digikey.com/short/z4wc7p $14
- (could go down with IRF4905 elsewhere)
- Board: $3-5?
- Nano: $5
- Screen: $4
- Heatsinks – depends on power level desired – figure $5-$20 for 1A - 15A

Heatsink Info

- MUCH LESS concern with 0.005 ohm devices….
- Heat works just like ohms law.
- Degrees C is the “voltage”
- Watts is the “current”
- Device is around 1.5 degC/watt (that is a heat “resistance”)
- Ambient 25, junction 125 – rise = 100. @20 watts. Max total “heat flow resistance” = 100C/20W = 5
- Need heat sink at 3 degC/W or less.

There are heatsinks out there.

DIGIKEY 2.5 inches high
$3
3.5 degC/w
Natural convection

Electronicsurplus.com
$8